External Research Report

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Acoustical Design of Medium Density Housing

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Project LR0514

Marshall Day Acoustics, Scion, University of Auckland, Enovate Consultants, Jasmax, ECubed, funded by the Building Research Levy

Acoustical Design of Medium Density Housing

Collaborative research project funded by the Building Research Levy

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PROJECT SUMMARY

By Tessa Phillips (MSc), Marshall Day Acoustics, March 2018

INTRODUCTION

Population growth, demographic change and environmental considerations are leading to increasing densification of housing in urban New Zealand. BRANZ, New Zealand's key independent building research organisation, is currently undertaking a research programme to help ensure future medium-density housing (MDH) meets the needs of New Zealanders. Previous feedback to BRANZ highlighted noise control as an important consideration for medium-density housing developments.

This collaborative research project "Acoustical Design of Medium-Density Housing" was proposed and funded by the Building Research Levy to help BRANZ better understand this area and help address the following BRANZ research goal and questions:

BRANZ 2016/2017 Goal and Research Questions, as listed for Research Programme 1 / Question 1 of [1]**:**

"Providing the building industry with the technical information to design quality, affordable and desirable medium-density housing (MDH) in relation to noise control:

- *What are the key issues around acoustics and noise control that will need to be addressed to provide for quality, affordable and desirable MDH?*
- *What existing information exists that can support good acoustic performance in MDH?*
- *What gaps are there with this information? Where is there a need for new knowledge? Where is there a need for improved access/uptake of existing information?"*

This summary document provides a brief overview of this research project and its findings.

RESEARCH METHODOLOGY

To provide a multidisciplinary viewpoint, the core research team, included expertise in acoustics, architecture and engineering from both consultancies (Marshall Day Acoustics, Jasmax, ECubed, Enovate/Kirk Roberts) and research organisations (Scion, University of Auckland).

The project was broken down into three stages.

- **Stage 1: Literature review** of the current state of play both here and overseas including: information currently available, regulations, and relevant research underway.
- **Stage 2: Consultation** with a broad cross section of building industry participants on perceptions of the key issues, information needs and how to address them. This was achieved primarily through an in-depth building industry online survey "Towards quiet housing" (over 600 respondents), but also through interviews, discussions and practical examples. Participants included those in housing design and construction, as well as those in planning, management, compliance, education and product development / supply.
- **Stage 3: Analysis** of the Stage 1 and 2 findings to provide a comprehensive picture of the key issues and information needs, along with recommendations for solutions that could address them.

The final research report and appendices, completed 30 June 2017, detail the full findings from all three stages. The focus was on building design and construction to provide reasonable protection from everyday noise, rather than the design of planning /zoning requirements.

BACKGROUND CONCEPTS

As housing density increases, the possibility of occupants being annoyed by sound related issues increases. This includes potential annoyance due to noise (unwanted sound) from neighbouring dwellings and the broader neighbourhood environment (e.g. traffic noise). Another consideration is the desire for reasonable acoustic privacy, with the closer proximity of neighbours.

Excessive noise levels can significantly affect the amenity of a dwelling and the health and wellbeing of its occupants (see World Health Organisation [2-4]). Designing and constructing dwellings to provide residents with a reasonable level of acoustic comfort (privacy and protection from noise) is very important not only for resident health and wellbeing, but also the long-term desirability of medium-density housing – a factor that was overwhelmingly agreed on during consultation.

Key areas that need consideration in the design of dwellings are:

- **Inter-tenancy noise:** reducing transmission of airborne and impact noise (e.g. footfall) from other attached occupancies and from common spaces such as corridors, foyers and internal carparks;
- **Environmental noise:** protection from external noise through the building envelope (including façade, windows/doors, roof, external vents etc.)
- **Building Services noise:** mitigating noise from plumbing, HVAC equipment and other building services (e.g. lifts, mechanical doors)

Acoustical design needs to balance cost with providing reasonable rates of occupant satisfaction without over-engineering or producing difficult-to-build designs.

KEY FINDINGS

The consultation process revealed that the biggest issues centre around knowledge levels across the building industry as a whole. Key issues identified included:

1. **Needing to raise baseline knowledge across industry**: Although there is a general awareness that noise needs to be addressed, there is less knowledge of how best to address it, with failures at any stage in the dwelling's planning/design/construction having a significant effect on overall outcomes. Feedback indicated this was a big issue.

   This is especially an issue in NZ where residential building has largely focused on detached low-density housing where noise control as part of building design has not been so relevant. Education, training, and readily accessible information is therefore a key requirement to boost base level knowledge and broader understanding, especially for those in the residential building industry moving from design/construction of detached housing to attached MDH.

   For example: even when those involved in a building's design do have a good knowledge of designing for acoustics
   a) if developers / project managers don't give it sufficient priority or early consideration (or understand the cost benefit) it cannot be well integrated into the whole building design, critical for good acoustic outcomes. This can lead to acoustic needs becoming a costly after thought and/or only addressed to low standards;
   b) if installers/contractors aren't aware of basic concepts, simple workmanship errors can significantly reduce the actual performance outcome of any design.

2. **Regulations:** Currently there is a lack of clarity and consistency around NZ acoustic regulations and room for additional coverage. However, efforts to update the New Zealand Building Code (NZBC) to address these issues have yet to occur, despite efforts to reach consensus for over 15 years.

   Currently residential inter-tenancy noise is addressed through the NZBC Clause G6 (G6) introduced in 1992 with G6 and its supporting compliance document [5] unchanged since 1995. G6 addresses some aspects of airborne and impact noise between abutting occupancies, with interpretation and compliance requirements varying significantly across the country. For example: Auckland Council requires design signoff as well as on-site acoustic testing post construction of a representative sample of multi-storey MDH to verify compliance of whole system performance, whereas other councils may rely on building element design / product specifications only.

Protection from environmental noise is provided for in some noisy areas in some NZ district plans, but not in a consistent way. It is managed through a range of different requirements relating to façade performance, internal noise levels to be achieved and ventilation requirements. Better consistency would be beneficial through inclusion in G6 or as part of new National Planning Standards (part of 2017 amendments to the Resource Management Act).

Industry feedback revealed a wide mix of feelings about existing regulations, though only a tiny proportion felt regulations were excessive, and many wanted improvement. For example, in relation to Clause G6, the "Towards Quiet Housing" survey question 7 indicated that amongst those with an opinion, less than 2% thought the current minimum performance requirements were too high, and over 55% felt that either additional areas needed to be included and/or minimum performance levels raised.

Even where the regulations were thought satisfactory as a minimum to help address affordability, better support was wanted to help understand the criteria and how to meet and/or exceed them cost effectively. Also, there was a desire for more understanding of end-user (housing occupant) needs and what satisfaction rates NZ's current minimum regulations provide.

3. **Lack of readily accessible, NZ specific, independent information**: Although there is a great deal of technical information on acoustical design scattered internationally, there is little independent information on meeting NZ specific requirements such as local regulations, geographic considerations (seismic, climate), and using the most readily available resources including materials and skillsets.
   For example, central European based information on heavy weight construction in non-seismic zones with good acoustic performance is readily available. From an acoustic performing point of view this is relevant in a NZ context, but engineers also need to ensure that high mass buildings are designed to withstand seismic movements. Light weight construction is sometimes preferred for seismic reasons. However, with less mass to impede noise transfer, lighter weight construction needs extra attention in design and construction details to achieve good acoustic performance.

   At present, there is common reliance on a few proprietary NZ product manuals to understand how to meet NZ acoustic requirements. Although these are often appropriate, and are an important link in the design / compliance chain, there was a strong desire for much more access to independent information on general concepts and generic solutions (including a far greater range of "Acceptable Solutions" as part of compliance documentation). It was felt this would help with product comparison, competition and affordability and help practitioners understand the full range of options available, as well as when to seek specialist advice.

   More information was wanted across all areas, but especially inter-tenancy floors, walls and integrated building solutions (see next section). This report provides details of specific technical information needs across all areas, information currently available and gaps in knowledge.

4. **Integration issues:** Currently acoustic considerations are often not included early enough in the building design process. Given the impact of the whole building design on acoustic outcomes, the best and most cost-effective solutions for the overall project require good integration of acoustic with structural and fire protection requirements, but also as part of addressing other areas of internal comfort (good air quality, temperature and moisture control, natural lighting), sustainability (e.g. energy efficiency) and even aesthetic trends. Feedback noted lack of integration between the various fields generally as an issue, with better awareness of the interplay between disciplines needed.

   There was a strong desire for more information on integrated systems and products that can work well together to meet multiple building code requirements. Research that helped develop cost-effective, practical building systems that meet multiple requirements was seen as one of the best ways to reduce costs while providing better quality.

5. **Understanding end-user needs:** The proportion of NZ end-users who live or have lived in MDH has only recently become significant, and the proportion will only increase in future. This means the feedback loop to drive market demand for improved sound insulation is only now coming fully into play, including to change developer focus, drive new building product development or inform regulatory requirements.

   In fact, very little NZ-specific, acoustic related, post-occupancy information is available that directly links subjective and objective acoustic performance outcomes. Although overseas experience is useful in the interim, understanding satisfaction rates and performance outcomes with local building techniques, constraints and requirements is very important, as noted in the large European COST Action study on residential building acoustics [6].

   The lack of feedback between end-users and industry participants (as well as between industry sectors) to better understand and improve building systems and regulations, was also noted as a wider industry issue.

RECOMMENDATIONS

Recommendations for immediate future action, centre on a few key areas:

1 INFORMATION DISSEMINATION

The first priority is that industry needs much more independent residential acoustic information readily and freely available as quickly as possible, independent of supplier information. There is plenty of technical information available, but it needs to be packaged so the most relevant information is easily available to different sectors of industry, in an appropriate format to provide ongoing guidance and support.

Consultation showed people want up to date, online information from an independent source with latest best practise and research - for example a site supported by BRANZ or MBIE (Ministry of Business, Innovation and Employment). This should be combined with greater regulatory support through improved compliance documentation e.g. from MBIE (who are responsible for the NZBC) and building consent authorities such as councils

An online "Quiet Housing Hub, is suggested as the most effective means of delivering the information, potentially as part of a broader acoustic information hub. This could provide a central reference point for the most relevant information, arranged in a modular fashion with guidance material which can be gradually expanded and more easily updated than mandatory regulatory documents.

Ideally this hub would expand from the general concepts needed for each topic and sector of industry, to include modules with best practice generic constructions (including junction details) that provide good acoustic performance for simpler builds. The UK's "Robust Details" system and handbook [7] is also discussed in the report as an example framework. Robust Details was the most commonly referred to useful overseas solution during consultations. Feedback mechanisms could also be incorporated so that the hub can become an integral part of ongoing research.

The hub would be a useful repository both in the absence of immediate regulatory change, and in support of any future changes. The NZBC Clause G6 update process has produced some useful NZ specific materials covering many of the areas highlighted during the project's consultations. Making the information available for guidance would be extremely valuable, especially as people are wanting more information on generic solutions and achieving above the current code minimum. As guidance information, practitioners would still need to follow compliance processes such as design signoff and/or on-site testing for approval, so there is still a desire for more formal "Acceptable Solutions" that also meet compliance needs.

Once the hub is created, it is recommended that a promotion and education phase be initiated to help with raising awareness of the hub and increasing baseline knowledge levels. Once knowledge levels improve, there is potential to use some form of rating system (e.g. star rating) to help inform end-users of acoustic performance outcomes, to help provide transparency and incentivise better quality.

2 RESEARCH AND DEVELOPMENT

In response to the industry survey and current state of play, recommendations are made for research areas thought to be most immediately beneficial. In summary, the recommendations include:

- **Undertaking NZ post-occupancy surveys** that combine subjective and objective acoustic performance. Such surveys would give feedback on the overall acoustic performance of particular construction designs, enabling verification of building design performance and input to regulation. This could be part of broader and ongoing MDH post-occupancy building performance research.
- **Enabling better building designs and solutions.** This includes developing acoustically better systems from existing construction designs and adapting new systems for use in New Zealand. In the case of both proven overseas solutions and local innovations, good information on performance, buildability, local compliance and cost-effectiveness are needed for widespread adoption. Methods and tools are also needed to enable incorporation of performance requirements from other disciplines (e.g. fire, structural), and to make information readily available.
- **Developing better acoustic prediction tools**. This entails adoption and further development of prediction methods which are showing good promise as acoustic prediction tools for sound insulation. Prediction is very important, especially for complex designs (including light weight construction with its multiple connections and components), to help designers understand likely performance.

The report looks at each of these areas in further detail.

3 REGULATIONS

The industry feedback indicated there is certainly support across all sectors to improve NZ's regulations related to building acoustics. The report urges that efforts actively continue in this direction. In the meantime, it is hoped the introduction of an information portal will help get people more familiar with what can and can't be easily achieved and avoid unnecessary mistakes, which should help drive a general improvement in quality. Hopefully any future shift in regulations will then come more easily.

CONCLUSIONS

This project has collated a large amount of information on the current state of play and the most relevant information resources, needs and gaps as they relate to noise control and acoustics in NZ medium-density housing. The extensive industry survey and other consultation includes qualitative and quantitative data covering the full range of perceptions in this topic from across NZ industry.

The suggested online Quiet Housing Hub format should be able to utilize this information to provide an invaluable expandable resource to deliver technical information to industry, to support better noise control for medium-density housing and any future changes to acoustic regulations. Information from the research areas highlighted can also be better fed back to industry via the hub.

However, building acoustics cannot be considered alone - for quality, affordable, desirable medium-density housing, careful integration is needed with other areas of planning, design and construction.

REFERENCES FOR SUMMARY

1. BRANZ, *Building Research Levy Prospectus 2016/2017*, BRANZ, Editor. 2016.
2. World Health Organisation. *Guidelines for community health*. 1999; Available from: http://www.who.int/docstore/peh/noise/guidelines2.html.
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5. Department of Building and Housing, *Compliance Document for New Zealand Building Code - Clause G6 - Airborne and Impact Sound*. 2006, vicbooks: Wellington. p. 20.
6. Rasmussen, B. and M. Machimbarrena (editors), *COST Action TU0901: Building acoustics throughout Europe. Volume 1: Towards a common framework in building acoustics throughout Europe*. 2014, COST - European Cooperation in Science and Technology.
7. Robust Details Ltd. *The Robust Details Handbook [online]*. Available from: www.robustdetails.com.

The full report includes extensive references and links to further information in all areas.

1 INTRODUCTION

This research project aims to help BRANZ understand the current issues and information needs around building acoustics and noise control in relation to the design and construction of medium-density housing (MDH) in NZ. Some recommendation are also offered on what can be done to help the building industry produce good outcomes in this area. The report is broken up as follows

- Chapter 2 Research Topic: Defining the parameters of the project, specifically the research topic as defined by BRANZ and the scope limitations applied.
- Chapter 3 Methodology: Explains the methodology used during the project, including the three core phases of the project – Stage 1 literature review, Stage 2 industry consultation and Stage 3 analysis.
- Chapter 4 Background Concepts: A quick run-down of key concepts relevant to residential building acoustics.
- Chapter 5 Key Findings: Outlines the key findings in relation to the state of play in NZ, key issues and information needs as they currently stand.
- Chapter 6 Proposed Future Action: Some recommendations for future courses of action, and solutions that could be developed, based on the findings.
- Chapter 7 Conclusions

The main body of this report is intended to provide a consolidation of the research findings and analysis. Detailed research results (eg full literature review details and actual consultation feedback) are provided for reference as appendices.

Appendices included are

- Appendix A – References: list of references for the body of report and appendices C-E
- Appendix B – Original project proposal
- Appendix C – Acoustics and noise control fundamentals: for reference, including glossaries
- Appendix D – Factors influencing internal acoustic quality: more detailed information on NZ regulations, design areas relating to noise control and interaction with other design areas, as gathered during Stage 1
- Appendix E – Information Resources: detailed information on existing resources and information sources both in NZ and overseas – including standards, design guides, information tools, ongoing research, and acoustic and building performance related organisations – primarily gathered during Stage 1
- Appendix F – Sample solution module: example of a module delivering sample construction details for delivery through the 'quiet housing' hub
- Appendix G – Stage 2 industry consultation – full methodology, survey analysis by question, interview feedback and practical case studies collected - (full survey response counts and tables of anonymous comments are available upon request)

Some interesting quotes from the industry survey 'Towards Quiet Housing' are also scattered through the report and especially in Appendix G with the respondent's role and question number, e.g. ARCH, Q10, indicates a comment within an architect's response to Question 10.

Note: in this report the abbreviation MDH refers to Medium-Density Housing, and the references to G6 refer to Clause G6 "Airborne and Impact Sound" of the NZ Building Code.

1.1 RESEARCH TEAM AND ACKNOWLEDGEMENTS

This collaborative research project was undertaken by a group of researchers including acousticians, structural and mechanical engineers, architects, and scientists, as well as consultation with building industry representatives. This provided an interdisciplinary view, and helped highlight issues and tools that individual disciplines might not have otherwise identified

The core research team consisted of

Organisation	Key Researchers
Marshall Day Acoustics	Malcolm Dunn (Acoustician) Lead Researcher Tessa Phillips (Acoustician)
University of Auckland / Acoustics Testing Service	– Brian Mace (Engineering Lecturer) – Mike Kingan (Engineering Lecturer and head of Acoustics Testing service)
Scion – Crown Research Institute	– Grant Emms (Physicist), – Andrea Stocchero (Architect)
Jasmax Architects	– Prue Fea (Architect) – James Whetter (Architect)
Enovate Consultants	– Michael Newcombe (Structural Engineer)
ECubed Engineering	– David Fullbrook (Mechanical Engineer)

The team would like to acknowledge the assistance of many others within each of these organisations

Special mention must also go to the following for their many hours of advice and assistance:

BRANZ	- Kate Bryson, Richard Capie, and Anne Duncan – the key BRANZ contacts for this Project
Ministry of Business, Innovation and Employment (MBIE)	- Yasmin Merwood - Advisor for Building, Resource and Markets, Building System Controls at Ministry of Business, Innovation & Employment) for advice on the proposed update to Clause G6 of the NZ Building Code)

Industry Consultation

Thanks to BRANZ, the Acoustical Society of NZ, IPENZ, and the NZ Planning Institute for help with the distribution of our survey invitations.

Thanks to all those in the building industry who took the time to speak with team members about the project and the 600+ participants in our survey. Thanks to the following for contributing a little extra time to help with our efforts

- Dr Sean Smith (Napier University, Edinburgh), Dr. Stephen Chiles (Chiles Ltd acoustic consultant), Peter Horne (Design Acoustics), Rau Hoskins (designTRIBE), Jeff Mahn (National

Research Council, Canada), John Keen and Paul Williams (USG Boral), Cameron Baker (Jalcon Homes), Daiman Otto (TallWood), Richard Finley (NDY)

Special mention to the following who have been a little more involved across several stages of the project from the proposal stage.

Jeff Parker, Mark Smith	WPMA - Wood Processors and Manufacturers Association
Hamish Ewan, Hans Gerlich	GIB/ Winstone Wallboards
Stephen Hicks	Heavy Engineering Research Association
Rob Gaimster, Ralf Kessel	CCANZ - Cement and Concrete association NZ

2 RESEARCH TOPIC

The scope of this project is defined by the requirements of the BRANZ Research Programme of which this project is part. It is important to understand how the project fits in the broader context of MDH research efforts since acoustical design is only one aspect of MDH design.

The goal of the project is to help provide BRANZ with better understanding of the key issues and information needs in the NZ context, and what steps can be taken to aid the NZ building industry in the provision of housing with reasonable levels of acoustic comfort.

The key focus is on medium-density housing typologies where there are several shared building elements (eg walls, floors), requiring careful design to reduce noise transmission, especially 2-4 storey apartments. However, similar principles apply for other attached multi-unit dwellings (taller apartment blocks, 1-3 storey terraces, and semidetached housing) and detached dwellings.

This section provides details of the BRANZ programme, project specific goals, as well as clarification of scope boundaries applied.

Hobsonville apartments, Source: Jalcon

2.1 BRANZ RESEARCH TOPIC

> *"BRANZ is an independent and impartial research, testing and consulting organisation inspiring the building and construction industry to provide better buildings for New Zealanders. We achieve this by transforming insightful research into accessible actionable knowledge."*
> *- www.branz.co.nz/about_branz*

BRANZ is the steward of the NZ Building Research Levy. This levy is gathered as a contribution from all large NZ building consent applications and used to fund relevant building research. (http://www.branz.co.nz/building_research_levy)

In recent years, BRANZ has identified the current intensification of housing in NZ urban centres as an area worthy of further research. In 2016 they established a new research programme focussed on medium-density housing (MDH), as per page 8 of the BRANZ, Building Research Levy Prospectus 2016/2017 [1]:

> *"BRANZ Research Programme 1: Giving industry the tools to deliver medium density housing that meets the needs of New Zealanders"*

One area highlighted by industry feedback to BRANZ, was the need for more information in relation to noise control for MDH. This research project, "Acoustical Design of Medium Density Housing", was funded based on the call for proposals in this area (Pg 8, [1]), specifically:

> ***BRANZ Research Programme 1, Research Question 1:*** *"Providing the building industry with the technical information to design quality, affordable and desirable MDH in relation to noise control:*
>
> - *"What are the key issues around acoustics and noise control that will need to be addressed to provide for quality, affordable and desirable MDH?*
> - *What existing information exists that can support good acoustic performance in MDH?*
> - *What gaps are there with this information? Where is there a need for new knowledge? Where is there a need for improved access/uptake of existing information?"*

2.2 PROJECT SCOPE

The Building Research Levy funding for this project was awarded based on the proposal document submitted by a collaborative team lead by Marshall Day Acoustics. The parts of the project proposal that outlined the "project objectives", "project outcome" and "proposed methodology", are provided in Appendix B for reference.

As noted in the project proposal, this research project is considered to be the first step in a programme whose ultimate outcome is to enable the cost-effective construction of acoustically comfortable buildings that are also durable, warm, dry, cost-effective and attractive to live in. Therefore this project is primarily a needs assessment, identifying where current practices could improve, gaps and deficiencies in knowledge, plus key areas where future research and product development are needed.

As such this project does not aim to provide detailed design solutions or develop specific tools for delivery of information, but does recommend some actions for BRANZ to pursue. It is hoped these recommendations would help to increase the level of knowledge of the key participants in the building industry: developers, local authorities, architects, structural engineers, building services engineers, acoustic engineers, contractors, and manufacturers of building materials.

The primary focus of the project is noise control in medium density housing, in relation to the building's design and construction. It is important to clarify the boundaries under consideration, as there is possible overlap with several other areas.

2.2.1 MEDIUM-DENSITY HOUSING

What is meant by Medium-Density Housing? Although no strict definition is given in the NZ building code, the NZ Ministry for the Environment definition is:

> *"Medium-density housing means comprehensive developments including four or more dwellings with an average density of less than 350 m2 per unit. It can include stand-alone dwellings, semi-detached (or duplex) dwellings, terraced housing or apartments within a building of four storeys or less. These can be located on either single or aggregated sites, or as part of larger master*

planned developments" - http://www.mfe.govt.nz/more/towns-and-cities/medium-density-housing , 8 Nov 2016.

It is understood that BRANZ are also working on a formal definition as part of the broader research programme.

The key focus of this study will be on low level apartments (up to four storeys), dwellings which can expect to have several wall and floor/ceiling connections with one or more adjacent occupancies.

However, many of the same principals apply for terrace /semi-detached dwellings and also taller apartments (4+ storeys). Typically, the design of terrace housing is more simplistic acoustically than apartments as there is only shared Inter-tenancy walls, and it is possible to implement pre-packaged commercial solutions (eg standard inter-tenancy walls from manufacturers). Structural requirements for taller buildings tend to limit the structural materials used, though there will likely be greater structural connectivity for stability and seismic resilience. Requirements for external noise apply equally to all types.

2.2.2 BUILDING ACOUSTICS NOT ROOM ACOUSTICS

For this project, the focus is on building acoustics rather than room acoustics. Building acoustics focuses on sound transmission through the building's structure e.g. through walls, floors/ceilings, doors, windows. Room acoustics on the other hand focuses on the behaviour and perception of sound inside a room, and is more of an aesthetic consideration in the residential context e.g. the room sounds acoustically dead or is too reverberant.

Requirements for room acoustics are highly dependent on personal preference and room usage, can be modified to some extent by the resident through furnishings / surface treatments etc., and are not currently addressed in the NZ Building Code. By contrast sound transmission through the exterior envelope and between rooms is dependent on the building's construction which is outside a resident's direct control. However, the increased use of hard surface in homes and common spaces, resulting in long reverberation times and increased loudness is discussed briefly in section 5.4.5.

2.2.3 BUILDING ACOUSTICS NOT CONTOL OF NOISE SOURCES

The control of noise sources, through appropriate local planning rules or legislation, are all part of the overall picture of controlling noise in the residential context. (eg zoning residential areas away from noisy industrial zones, requiring factories to be built to limit noise at their boundaries etc, abatement methods for excessively antisocial noisy neighbours).

However, the focus of this project is reducing the effects on residents of everyday noise that a dwelling is exposed to (either from outside or generated within the building), through the design of the building.

As such consideration is not given to the design of planning rules, noise limits or mitigation of external noise sources, nor the use of sound barriers (eg fences). These have been taken to be outside the scope of this project.

Building placement in relation to external noise sources (eg road) and other buildings can have a large impact on internal noise levels, and sound levels for external living spaces (eg balconies, courtyards). It is important to ensure urban planners and architects take acoustical factors into consideration when planning a buildings location, position relative to site and noise sources, as well as room layouts. Although this is not the key focus of the project, the importance of this cannot be ignored and is discussed at a broad level.

2.2.4 INDUSTRY RATHER THAN END-USER CONSULTATION

Within the scale of the current project we could not include direct consultation with occupiers or those connected with the ongoing usage of dwellings (eg landlords/property managers/body corporates, noise control officers, real-estate agents). However, this is an area that is probably worthy of further investigation – see further research re post occupancy, section 6.2.2.

With the focus of this project being how to help provide technical information to industry, our consultation was mostly focussed on industry requirements but did include gaining industry perceptions of end-user needs since end-user needs should ultimately drive design requirements.

3 METHODOLOGY

This chapter presents the overall methodology used for this research project. The project was conducted by a cross disciplinary research team (section 3.1) and was broken down into the three stages outlined in section 3.2. Each of these stages is described in more detail in sections 3.3 to 3.5

3.1 RESEARCHERS

To get an interdisciplinary viewpoint for this project a core research group was assembled, incorporating acousticians, architects, structural and mechanical engineers, and acoustic researchers (see Section 1.1). Links with building industry representatives were also made to help ensure practical construction and implementation considerations are incorporate, though in practice the main industry representation came through the wide cross section of responses through during our survey.

Each of the key researchers could draw not only on their own experience but the knowledge of their colleagues and broader networks in each of the key disciplines. Regular meetings, communications, and reviews of each other's documentation aided identification of interdisciplinary concerns. 500 professional hours were allocated for this project, but in practice more time has gone into the project, since this is felt to be an important topic which needs to be addressed well.

3.2 PROJECT STAGES

The project was separated into the following three distinct stages:

Stage 1 - Literature review: aimed at determining the state of play of residential acoustical design in NZ (including key drivers, considerations, regulations, and related factors), along with current research and information available, both in NZ and overseas.
– July to November 2016

Stage 2 - Industry consultation: to gauge building industry knowledge in the area of noise control for MDH, and also perceptions of key issues, information needs, products and R&D needs, to help prioritise areas for attention.
– December 2016 to March 2017

Stage 3 - Development of solutions: consolidation of the information from the first two stages to recommend steps that should be taken to aid the development of quiet housing in NZ
- April to June 2017

A little more detail on each stage is offered below

3.3 STAGE 1 - LITERATURE REVIEW AND STATE OF PLAY

This stage included reviewing the relevant acoustic and noise control information as they relate to MDH, along with the meaning of 'acoustic quality' especially in the NZ context, starting with the minimum acoustic performance criteria required by current and proposed legislation, regulations and standards.

MDH design invariably involves a degree of compromise, with design and construction needing to address multiple objectives. Consideration was therefore given to the interplay between acoustic and other MDH design considerations (eg structural, fire, energy efficiency, thermal comfort & air quality, architectural, economic).

Also included was a review of resources that are currently available to the construction industry to help them meet and exceed current sound insulation requirements in NZ, and methods used overseas to inform their building industries (eg design guides, information tools). A summary of relevant building acoustics research areas being undertaken in NZ and overseas was also produced.

The information gathered by the research team was collated into a Stage 1 progress report. Most of the detailed information from that progress report, along with relevant extra findings during later stages, are included as Appendix B to Appendix E. Information from Stage 1 was used to determine questions to raise during the following consultation stage.

3.4 STAGE 2 – INDUSTRY CONSULTATION

Stage 2 was the industry consultation phase of this project, and aimed to identify the current state of acoustic knowledge in the NZ building industry, what industry wants and needs to know, as well as helping to prioritise the key areas that need addressing.

Three methods were used as part of this industry consultation phase:

SURVEY: The main method used was an electronic survey "Towards Quiet Housing", distributed to a cross section of the building industry. This included a mix of fixed choice questions (all with an option to comment) and open-response questions. This was primarily intended for qualitative feedback though some quantitative results were also obtained.

INTERVIEWS: In addition, several formal interviews were undertaken with groups that were less represented in the mailing list and research team. Key interviews were documented, with many other informal discussions also held.

CASE STUDIES: Practical examples of how acoustic considerations have impacted building projects were also included as mini case studies, for a variety of structure types and areas of consideration.

The consultation phase changed slightly from the original proposal plan, with a larger online survey undertaken and less formal interviews and case studies.

With over 600 respondents, the industry survey has generated a large amount of valuable data on industry opinions. Extensive comments show the wide range of issues and concerns perceived across the building industry. Formal and informal interviews have added to the depth of understanding and practical examples help to demonstrate various points.

Full documentation of the consultation as complete at the end of stage 2 is also provided in Appendix G. See Appendix G, Section G5 Conclusions, for a summary of the consultation findings. Reference to consultation feedback is made throughout this report. This includes the methodology of the survey and question by question analysis, and practical examples/case studies. Full Survey responses and all comments are collated anonymously in Appendix H which is available upon request from BRANZ. Topic areas covered by the survey were as follows:

Questions 1-3: Participant's Industry Role and Experience

Questions 4-9: Drivers of Acoustic Design (e.g. end-user needs, regulations, cost etc.)

Questions 10-17: Information and solutions (currently used and wanted)

Questions 18-20: Opportunity to share experiences and opinions

Note time constraints have meant we have not completely followed up on all possible avenues, and these could be pursued as part of the follow up to this project – e.g. respondents willing to offer further case studies or further interviews; follow up of further case studies that were identified but information was not available within the time frame of the project (e.g. Otago CLT building, Christchurch earthquake impacts)

3.5 STAGE 3 – DEVELOP SOLUTIONS

Stage 3 consolidated the findings of the first two stages, to identify and prioritize gaps and deficiencies in knowledge, methods and systems in NZ. This could then address the core BRANZ research topic questions relating to key issues and information needs (see chapter 5 for key findings).

In addition, outcomes proposed for this stage (see project proposal Appendix B) were to

- Determine appropriate dissemination methods for existing knowledge
- Identification of overseas solutions that could be utilized or modified for the NZ context
- Identify and prioritize additional research, tools and solutions needed.

See Chapter 6 Proposed Future Actions for a rundown of the final recommendations.

The core feedback from the industry consultation was prioritizing better access to NZ oriented independent (rather than proprietary) information and education to increase awareness and baseline understanding across the industry, along with clearer understanding of end-user needs. Access to more information on compliant, practical and cost-effective solutions across all structure types, and information on what to be aware of at different stages of the build process were also important through better generic guidance documentation and/or best practice guidelines, not just through product supplier manuals. A good range of products to meet these needs in practice was also important, with research to help development of solutions that work in the NZ context. Online, up to date, printable resources were preferred. Closing the loop between design and outcomes could also help with ongoing improvement of systems and regulations.

This meant one of the focusses of this stage was on the need to quickly develop a modular information hub focussed on residential building acoustics, which can be grown as resources are developed. Guidelines and frameworks used overseas were examined in some detail, especially the Robust Details framework used in the UK for acceptable solutions, as well as the NZ information people found most helpful. The types of information that should be included through the hub were collated and a sample framework for generic solutions created.

Specific topic areas requiring further information were also identified to help determine the most beneficial future research topics, with a leaning towards areas highlighted in the industry consultation.

During this stage, confirmation was also received that the long planned update to NZ Building Code Clause G6 is unlikely to be implemented for some time (G6 covers sound insulation / residential noise protection - see section 5.2.5.1). Considerable work has been put in during the code review process of the last 15 years, and the areas covered by the update do tally closely with many of the issues identified in this research. It would be appropriate to utilise some of the solutions developed as part of the G6 update process to be the basis for the initial modules. Approval has been granted to utilize some of the approved solution information contained within the proposed G6 compliance information, as samples for our generic solution mock guideline.

4 BACKGROUND CONCEPTS

To fully appreciate later chapters, it is helpful to understand some basics of acoustics and noise control, especially as they relate to residential building acoustics. This chapter provides a quick overview of key concepts– for some extra detail see Appendix C.

The MBIE run “reducing noise” page of the SmarterHomes website (www.smarterhomes.org.nz/smart-guides/design/reducing-noise/) gives a quick lay person’s guide, while the site highlights in simple terms the many aspects that must be considered in home design. Given the many competing factors it is easy to see how acoustical design can sometimes get lost in the mix.

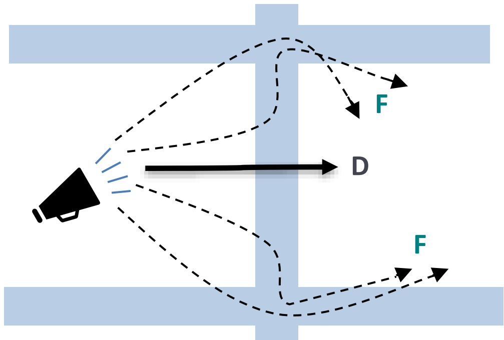
4.1 KEY CONCEPTS OF NOISE CONTROL AND ACOUSTICS

A book such as Marshall Long’s “Architectural Acoustics” [8] or Harris’s “Noise Control for Architects” [9] provides valuable additional reading for technical detail. www.who.int/occupational_health/publications/noise1.pdf also provides a useful background read online.

- **“Sound”** can be defined as vibrations that travel through the air or another medium and can be heard when they reach a person's or animal's ear. Sounds can have a range of frequencies (measured in Hertz, Hz) and strength (levels usually measured in decibels, dB, sometimes with a weighting corresponding to the sensitivity of the average human ear, dBA).
- **“Acoustics”** is the branch of physics concerned with the properties of sound. The term is also used to refer to the properties or qualities of a room or building that determine how sound is transmitted in it – “Building Acoustics” is the primary focus of this report
- **“Noise”** is usually defined as unwanted sound.
- **“Noise control”** covers strategies used to reduce noise pollution, or reduce the impact of noise (as is the key focus in this report). The key to successful noise control is good planning and design, since remedial measures are usually considerably less economic.
- **“Reflection / absorption / transmission”.** Sound hitting a surface will be partly reflected and partly absorbed. Depending on the construction behind the surface (mass, stiffness, connection types, dimensions and other properties of components), some of the energy will be absorbed within the element, some may be transmitted to other elements, and some will be re-radiated on the other side, as transmitted sound.
- **“Sound Transmission”** in buildings can occur in several ways. These are usually referred to as airborne, impact and flanking transmission.
  - airborne transmission – a sound produced in the air (eg voice, TV, traffic noise) is transmitted to the listener. Where a building element, such as a wall or floor, is situated between the source and receiver, the vibrations in the air on the source side cause the surface of the building element to vibrate. Vibrations can be transmitted through the element causing the opposite surface to vibrate and radiate a modified version of the sound to the receiver.
  - Impact transmission – When a building element is set vibrating directly (through an impact such as a footfall, door slam, furniture scrape or appliance vibrating), again the vibration can be transmitted through building elements and some energy re-radiated as sound to a receiver elsewhere.

- Flanking transmission – Any sound transmitted to the receiver not directly through the separating element is referred to as flanking transmission. These in-direct or 'flanking' paths between source and receiver, are harder to predict and can often significantly affect performance. Take as an example sound carried via a duct or common ceiling space between two adjacent rooms, or transmitted via a common floor slab – even if the wall directly between the rooms transmits no sound, some noise will still be heard in the receiving room via these flanking paths. Airborne and impact transmission is usually made up of sound travelling via direct and flanking path

Figure 1: FLANKING PATHS - Shows direct (D and solid arrow) and flanking paths (F and dotted arrows) in a building from an airborne sound source to receiving space. Based on Figure 1 of [10]



- "**Sound Insulation"** is the ability of building elements or structures to reduce sound transmission – for example increasing the sound insulation of a wall reduces the sound transmitted through it. (see Section 4.4 for more)

Sound transmission is not always intuitive, with small changes often having seemingly disproportionate effects. Think about how much more external noise you hear when just one car window is left fractionally open (the same effect as when you have air gaps in a wall), or how much louder a children's music box or tuning fork becomes when you place it on a table top (think vibrations from a speaker or TV mounted on an inter-tenancy wall amplified to a neighbour).

Design, material choices and workmanship can all have significant impact on the sound insulation performance of a building.

4.2 NOISE - HEALTH AND WELLBEING EFFECTS

In a residential context, noise rarely reaches levels that can cause hearing impairment (except for example very close to power tools and loud amplified music) but there are still considerable effects on health and wellbeing from lower levels of noise. Noise can interfere with a people's daily activities (e.g. communications, concentration, performance), disturb sleep, cause cardiovascular and psychophysiological effects (e.g. stress), and provoke annoyance responses and changes in social behaviour. For more - see the noise section of the World Health Organisation site - www.euro.who.int/en/health-topics/environment-and-health/noise/noise, and especially [3].

Source: Wikipedia commons
http://commons.wikimedia.org/wiki/Image:Ruído_Noise_041113GFDL.JPG

One of the key problems for all acoustic considerations is the subjective nature of noise. One person's enjoyable music can be another's noise! The volume and types of noise which cause people to become annoyed can also vary considerably. People's response to noise can depend on many factors such as: the type of noise (volume, spectrum), age, expectations, past experiences, perceptions about the noise producer (e.g. neighbour's behaviour or attitude), noise sensitivity and hearing loss, and even people's mood at the time.

Usually the concern is for excessive noise, but even too little background noise can be an issue in some instances, since it can have a positive masking effect – e.g. if background noise levels are very quiet, every introduced sound is heard more clearly, which can also be annoying or an issue for privacy [11]

So the aim in housing is to obtain good "Acoustic Comfort", i.e. that people are satisfied with the level of noise and experience sufficient privacy. Buildings with good acoustic quality provide acoustic comfort to most occupants, with better quality achieving higher satisfaction rates.

As noted in Q4 and Q9 of our survey, end-user requirements in relation to noise were perceived to be highly variable, from not being too concerned through to it being a critical consideration.

"The potential impact of mixed occupancy in MDH needs to be fully understood. Differences in age group will generate different life styles. One inconsiderate person with bigger woofers than The Grateful Dead can turn all their neighbour's lives to mush. Inter-tenancy noise controls are archaic and determine that a thudding bass delivering the equivalent of water torture is well within limits. " - [ARCH,Q9]

4.3 RESIDENTIAL NOISE MANAGEMENT

The negative health and amenity effect of noise mean that most countries require dwellings to be planned, designed and built to reduce everyday noise to reasonable levels. The two primary areas to address are:

- External noise – adequate protection from external noise sources such as traffic, outdoor activities or from other properties
- Internal noise – adequate protection from noise both from attached tenancies and other sources within the same building (neighbour noise)

These are usually achieved through planning restrictions and requirements to meet certain building regulations.

- Planning restrictions: Zoning rules and limits, and the arrangement of buildings, can help reduce the noise levels reaching dwellings from external sources (eg traffic, commercial, industrial ...).
- Building regulations/codes: Specify acoustic performance requirements for certain aspects of the building design and construction. The building layout, design and construction all determine how sounds (either from outside or inside the building) are transmitted to and from areas where quiet and privacy is required. Regulations for dwellings usually address inter-tenancy walls/floors but can also cover other requirements e.g. noise with common spaces (eg halls, foyers), façade/exterior envelope performance, building services noise (mechanical and plumbing), internal walls, reverberation times in shared spaces (eg halls/stairwells).

source Wikimedia commons - https://commons.wikimedia.org/wiki/File:Quiet_Zone_4889090049.jpg

Excessive noise from short term circumstances (e.g. construction noise, anti-social behaviour such as loud, late parties) is usually handled independently from everyday noise.

Countries have treated the problem in different ways, using different combinations of planning and building regulations, and even social protocols (e.g. guidelines for neighbourly behaviour such as www.highdensityliveability.org.au/building_complex_neighbour_protocols.php). Many different metrics to measure sound levels and sound transmission are also used. The minimum building standard required can also vary significantly. [12] demonstrates the wide variation even just within Europe.

Compliance methods also vary significantly between countries but usually involve some combination of

- approved solutions, construction details which if used are deemed to meet the requirements,
- acoustic testing of a representative sample of completed dwellings to verify compliance
- getting approval of designs by certified professionals,
- on-site monitoring of construction via checklists or suitably qualified inspectors as part of the certification process

Some countries also provide 'rating' or 'classification' schemes which can rate a dwelling's sound insulation using defined categories, providing more information about a building's acoustic performance – for example good / better / best or Grades A/B/C.

Although end user needs in relation to noise should be the primary driver for acoustical design, in practice the building industry usually work to minimum building regulation requirements unless pushed by individuals involved in the building project or market pressure to exceed them. The issue, when setting minimum standards, is to find a balance between ensuring most residents have adequate protection from noise, but also that buildings are not over engineered - whereby additional costs to incrementally improve the sound insulation outweigh the benefits for most end users and significantly affect provision of basic housing needs.

4.4 SOUND INSULATION

Sound Insulation is the ability of building elements to reduce sound transmission.

Sound insulation is not just about adding more 'batts' but is a property of the whole building element and how it is connected to other building elements.

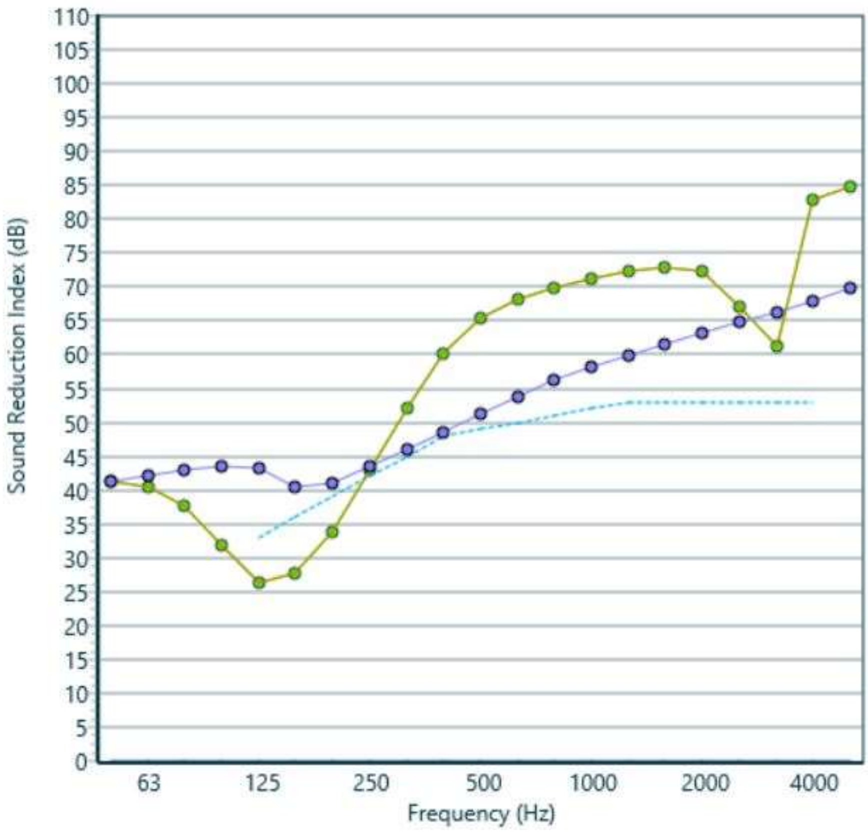
Using a plain wall as an example, the sound insulation achieved can depend on the dimensions and physical properties of the framing/blockwork, facing types, cavity, insulation / sound absorbing material, fixings, penetrations, air gaps, sealants, as well as the distances between components and connection to other elements (floors, ceilings). Resonance effects can also occur, both within air cavities and in solid components, significantly increasing vibration transmission at certain frequencies.

The main methods for reducing sound transmission include:

- **Sealing air gaps:** to remove direct air paths through or around a building element (e.g. using flexible sealants that won't crack where wallboards and floor/ceiling meet; rubber seals around windows / doors, sealing around penetrations for things like pipes, power outlets)
- **Increasing mass**: it takes more energy to vibrate more mass, however increasing mass alone can only go so far in practice (eg excess weight, material costs, structural limitation)
- **Adding absorption:** adding fibrous material in cavities reduces sound build-up and dampens low frequency resonances.
- **Adding damping:** to dissipate energy as heat as vibrations move through solid building elements, e.g. adding damping compounds between layers of material or using material with more inherent damping.
- **Incorporating isolation / de-coupling:** physically separating solid components from one another, to minimize the conduction of vibrations e.g. double stud walls and floating floor systems. Care must be taken to avoid unplanned bridging paths across isolated components. Where connections points are needed, suitable isolation must be incorporated (eg mechanical de-couplers linking double stud walls to meet structural needs; resilient clips used to fasten wall boards to framing; acoustic underlays or battens on rubber supports separating hard flooring surfaces from the floor structure)
- **Reducing resonance effects:** different components of a system have natural resonances (e.g. a stiff wall board will have certain frequencies where they resonate and transfer sound well). Combining different components with mismatched properties (impedance) can help even out the overall frequency response.

It is important to understand that there are many contributing factors, and the interplay between them is not always easy to predict and can be counter intuitive – For example as shown in Figure 2, the low frequency performance of a bare concrete block wall (in purple) is reduced when lined either side with 13 mm plasterboard on 40 mm battens without insulation (shown in green).

Figure 2: Comparison of sound reduction by frequency band of bare concrete block wall (in purple) and lined either side with 13 mm plasterboard on 40 mm battens with no insulation (shown in green). ***Source INSUL, Marshall Day Acoustics***



It is important to remember that in practice, **there is no such thing as 'soundproof' and use of the word can lead to unreasonable expectations**, as in reality there is always some degree of sound transmission.

The importance of details

Because of this, final designs need to provide full details which should be carefully adhered to during construction, to achieve the predicted sound insulation outcome. Unplanned-for connections through lack of detailing, workmanship errors such as screws bridging isolating layers or airgaps left unsealed, material substitutions, and many other seemingly minor changes can have significant impact.

By the same token, small changes in the arrangement and choice of materials can yield large improvements in sound insulation with little or no increase in cost which is where professional advice can be invaluable.

4.5 SOUND INSULATION DESCRIPTORS

There are many different metrics in use to quantify sound insulation performance. Sound insulation descriptors are specified by standards authorities such as International Standards Organisation (ISO) and ASTM International (formerly the American Society for Testing and Materials) and are a key component of sound insulation regulations. These single figure values give a quick tool to assess and compare sound insulation.

e.g. New Zealand, US and Canada use the ASTM descriptors "Sound Transmission Class" (STC) rating for airborne transmission and "Impact Insulation Class" (IIC) rating for impact transmission, whereas Australia, European and most other counties use various different ISO 717 descriptors such as R_w, $D_{nT,w}$, L_w etc. (see Appendix C2.4 for more).

Descriptors can be either:

- Laboratory based: describe the sound insulation performance of a building element in idealised testing conditions.
- Field based (The terms “on-site”, “apparent” and “in-situ” are also used): describe the actual performance of a built construction - the overall sound insulation effect between two spaces including through shared elements and flanking paths.

Descriptor values can be

- measured using standardised acoustic tests, or
- estimated through prediction modelling either using experience, calculations or software tools
    - for an element: by assessing the overall transmission loss through the components of the element and their configuration
    - for a whole construction field assessment: by combining the sound transmission loss through individual building elements and predictions of flanking effects for the whole construction

Limitations of Sound Insulation Descriptors

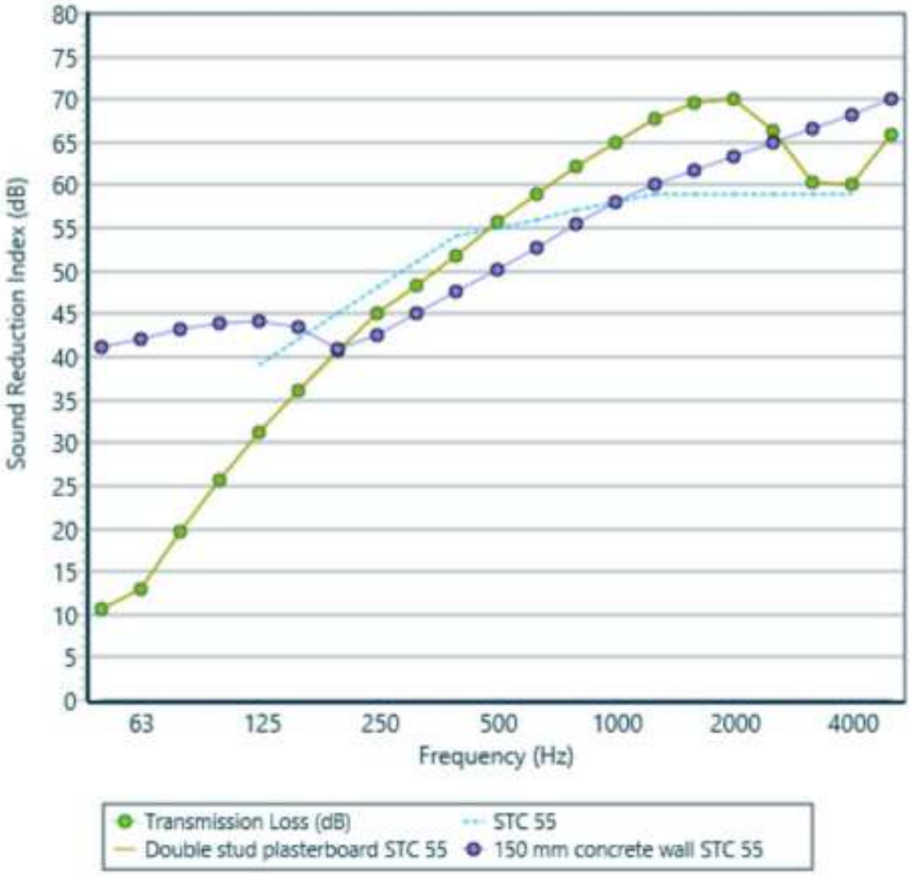
Because these single figure values combine information across the full frequency range, two building elements with the same sound insulation descriptor value can have quite different frequency responses. They also only cover a limited frequency range (the range to used is defined by the relevant standard, few consider below 100 Hz or above 4000Hz).

For example: The ASTM E413 standard for rating sound insulation (developed in 1962, including STC) describes the limitations of its use *“These single-number ratings correlate in a general way with subjective impressions of sound transmission for speech, radio, television, and similar sources of noise in offices and buildings. This classification method is not appropriate for sound sources with spectra significantly different from those sources listed above. Such sources include machinery, industrial processes, bowling allies, power transformers, musical instruments, many music systems, and transportation noises such as motor vehicles, aircraft and trains. For these sources, accurate assessment of sound transmission requires a detailed analysis in frequency bands”.*

For a better understanding of the actual performance, full acoustic test data by 1/3 or 1 octave frequency band for a wider frequency range can give a better picture of the actual transmission loss.

For example: STC values are calculated by comparing sound reduction index measured in frequency bands with reference STC curves and finding the closest match using specific criteria. A light timber frame wall and concrete wall may have the same “STC rating” but the timber wall may not block low frequencies as well as concrete and the concrete wall may not block high frequencies as well as the timber wall. Figure 3 shows an example of the results for a double timber stud wall and a concrete wall both rated STC 55, along with the STC reference curve.

Figure 3: Concrete vrs lightweight wall performance. sound reduction curve for a double timber stud wall (green) and a concrete wall (purple) which are both rated STC 55, along with the STC 55 reference curve (light blue dashes). ***Source: INSUL, Marshall Day Acoustics***



Although setting limits based on sound insulation descriptors is the most commonly used regulatory mechanism, because of these limitations and the subjective nature of people's assessment of noise, there is not a tight correlation between the descriptor and people's annoyance levels in any single situation, just trends across large samples (see discussion in [12]]. There is some ongoing international research looking at alternative descriptors which might provide a better correlation for different construction types (see current research in Appendix E3.4).

Non-destructive testing

Although the prediction of sound insulation is not always straight forward, and the impact of workmanship on construction can be significant, measuring the sound insulation outcome is reasonably straightforward and has the advantage of being a non-destructive test. Most of the sound insulation descriptors in common use defined methods to measure outcomes both for elements in laboratory situations and in the field. In principle, these tests involve a qualified tester:

1) **For testing airborne noise**: generating and measuring a very loud noise in a source room (e.g. pink noise from a speaker)
   For testing impact noise: generating a standardised impact in a source room (e.g. using a standard tapping machine)
2) Measuring the sound levels in the receiving room (must be above background noise levels)
3) Measuring the background noise levels

4) Performing standardised calculations to determine the relevant sound insulation descriptor value (sometimes compensating for the shared surface area or properties of the spaces involved, depending on the standard in use).

Tapping Machine. ***Photo: Tessa Phillips, MDA***

4.6 ACOUSTICAL DESIGN

As noted in section 4.4, the sound insulation performance achievable depends on the layout and structure of the building with suitable details for building elements and junctions. It is therefore imperative that acoustic considerations are included from the earliest stages of building projects. For instance, if it is determined later in a project that an inter-tenancy wall or floor needs a greater depth or alternative construction to meet sound insulation requirements, the knock-on effect is significant to the whole project.

Predicting sound transmission for a building design is not always straight forward, and for multi-unit apartments professional advice is usually advisable to confirm that all aspects have been considered and to check design details – whether through an independent acoustical consultant, or acoustic expertise within a project's existing architectural or engineering firm. Construction errors can also have a large effect on the final building performance, so it is generally prudent to design to a slightly higher level than required to provide some tolerance.

Usually mitigation after the fact is costlier than the incremental changes needed to design good sound insulation performance in the first place and undertaking relevant monitoring of the construction.

Acoustical design work consists of:

1) Determining the acoustic performance criteria needed to meet end user requirements or expectations (i.e. should the aim be code minimum or higher, do other areas need to be considered in this particular case)

2) Working with other design disciplines through the project's design phase to ensure designs will meet the acoustic criteria as closely as possible (certainly to minimum regulatory requirements, but where needed exceeding these), while also meeting other building constraints such as structural, fire protection, ventilation (including for air quality and thermal comfort), energy efficiency, water tightness, economic and even aesthetic.

3) Where necessary, certifying the final design meets requirements. Post construction, pre-occupancy acoustic testing or 'commissioning' may also be needed to ensure compliance.

5 KEY FINDINGS

5.1 INTRODUCTION TO FINDINGS

This chapter provides an overview of the current state of play for acoustical design in relation to medium-density housing (MDH) in NZ, including key issues and information needs. The aim is to address the BRANZ research questions, repeated here for clarity

BRANZ Research Programme 1, Research Question 1: *"Providing the building industry with the technical information to design quality, affordable and desirable MDH in relation to noise control:*

- *"What are the key issues around acoustics and noise control that will need to be addressed to provide for quality, affordable and desirable MDH?*
- *What existing information exists that can support good acoustic performance in MDH?*
- *What gaps are there with this information? Where is there a need for new knowledge? Where is there a need for improved access/uptake of existing information?"*

  - BRANZ, Building Research Levy Prospectus 2016/2017, Page 8 [1]

The chapter is arranged as follows:

- First an overview of the current state of play (Section 5.2) and existing information available in this area, both in NZ and internationally, including feedback from the NZ industry consultation conducted.
- Section 5.3 summarises the general issues and information needs identified that most affect the development of quality, affordable and desirable MDH in NZ in relation to noise
- Section 5.4 provides a tabular summary of specific technical information that needs to be readily available, along with current information gaps and improvements needed, arranged by topic

This provides a consolidation of the research undertaken, and the research team's interpretation of the results. The Appendices provide fuller details of the literature review and industry consultations conducted during Stage 1 and 2. Reference is made to the relevant Appendix sections for more in depth information. The following chapter 6 then makes some suggestions to address these issues and needs as well as priority research and development areas

Companion reading – COST Action TU0901

New Zealand is not alone in trying to figure out how best to address sound insulation needs. Although a common refrain amongst those we spoke to during our consultation was "do what they do in Europe / overseas where surely they deal with this better", the reality is there no unified approach in Europe or Internationally. Local building methods and histories have led to varying outcomes, solutions and issues; regulatory and compliance differences; and different standards used – these all lead to difficulties for trade, development and exchange of experience and construction data.

In fact, a useful companion to this NZ report is the two publicly available e-books produced by the European research project COST Action TU0901: Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions, available at http://www.costtu0901.eu/ which aims to establish a common framework to address these differences.

They provide extensive references to further reading in many relevant areas. The volumes include comparison of regulations and standards used in Europe, estimating translation of descriptors, classification schemes in use, development of a post-occupancy survey for international use, correlating subjective and objective measures, use of testing and construction monitoring, and common errors and good practice for design and workmanship. They also provide details of different constructions used across Europe and their performance (Volume 1 chapter11 (primarily heavy weight), and volume 2), and finally future research areas being addressed.

These 2 volumes even include some NZ, Australian, and Canadian comparisons, but also note the unlikeness of a common framework for some considerable time. However, we can still learn from overseas experiences to improve things in NZ, and watch developments in overseas research to incorporate in the future see appendix E3 for a full rundown of ongoing research).

Holistic approach

The original project proposal anticipated perhaps more of a focus on technical details required for different construction types. However, it became apparent early in the project that the key issues are really more systemic, and addressing factors holistically, across the whole building industry rather than just the technical details required of acousticians and designers, should provide benefits most quickly, while further technical information is developed. Some specific areas where additional information / research are needed are highlighted, with the focus mainly on boosting baseline awareness and understanding across the industry, increasing access to independent NZ specific technical information and research which can aid the development of cost-effective, robust, NZ compliant and appropriate integrated building solutions.

5.2 STATE OF PLAY

5.2.1 STATE OF PLAY INTRODUCTION

This section aims to present an overview of the current state of play of acoustical design, as it relates to NZ housing, as background to identifying key issues and gaps (presented in sections 5.3 and 5.4). This section also addresses the BRANZ research question on what “existing information” is available.

From a residential building perspective, noise as an environmental and health issue is primarily addressed in NZ through legislation, with

1) **inter-tenancy noise** (neighbour noise) addressed by Clause G6 of the NZ Building Code which specifies minimum requirements for the performance of building elements between occupancies,
2) **environment noise** addressed through the Resource Management Act, and subsequent district plan and resource consent requirements.

The introduction of these two pieces of legislation in 1991 also corresponded with the beginning of a period of significant change in the composition of New Zealand housing stock towards higher proportions of medium and high density dwelling types.

Section 5.2.2 offers a brief history of noise in the NZ residential context, including housing types and regulatory requirements to better understand the NZ context. Industry perceptions of drivers for acoustical design are covered in section 5.2.3.

General areas influencing internal acoustical quality are summarised in section 5.2.4, current legislative requirements are summarised in section 5.2.5, and integration with other fields /regulations in section 5.2.6. More in-depth information on all these areas are available in Appendix D. Finally, other tools for promoting higher quality are noted in section 5.2.7.

Information sources currently available to support residential acoustic design are discussed in Section 5.2.8, including NZ specific resources as well as those used overseas and current research, with Appendix E tabulating fuller listings of resources and research. Finally, a summary of areas covered in the NZ building industry consultation stage 2 of this project is provided in sections 5.2.9 and 5.2.10.

5.2.2 CONTEXT

As noted in COST Action TU901 [12], the outcomes, issues, expectations and regulations selected in different countries vary significantly based on the historical context, geography, and building techniques used, both traditionally and for more modern developments. Therefore, a brief history is presented here to put the current state of play into context.

5.2.2.1 "NOISE" 1974

Noise has long been recognized as an issue in regards to health in NZ, including as a form of air pollution, but has not always been directly regulated for.

For example the 1974 NZ Board of Health "Report No.21: NOISE" ([13], available in the MOH archives at http://www.moh.govt.nz/NoteBook/nbbooks.nsf/0/8445A3FD0DA5FF204C2565D7001870E9/$file/noise.pdf), highlighted the then state of play, noting scattered and infrequent reference to noise in legislation, the limitations in options to address noise, and limited expertise available in the area. In relation to providing a quiet internal home environment and addressing community noise in general (chapter 2 and 6 of [13]) the report recommendations included in summary:

- the need for increased protection of residents from noise through suitable enforcement and amendment to local authority regulations and bylaws (eg zoning; noise limits; time restrictions; long term planning; reducing noise at the source as much as possible) and the adoption of suitable acoustic standards in NZ to set appropriate levels.
- the need for building controls in relation to noise since this was not addressed through the then widely used standard NZSS1900 (Model Building Bylaw) adopted by most local authorities, who issued building permits. [It should be noted that fire protection requirements between occupancies, usually concrete, often provided some degree of sound insulation as a by-product, at least above the level of standard internal walls/floors.]
- requiring reduction of noise from the internal source where practical (including appropriate placement and insulation of mechanical services and plumbing, quieter appliances)

Common Law in relation to 'nuisance' and 'negligence', along with 'nuisance' clauses in the Health Act and 'objectionable use' provisions in the "Town and Country Planning Act" could be called upon in regards to regulating noise but were not a straight forward path [13].

Provisions for control of noise sources began being more widely introduced especially under the Town and Country Planning Act 1977

5.2.2.2 NZ STANDARDS

The first NZ specific acoustic standards were introduced in 1977 as NZS 6801and 6802 relating to measurement of environmental sound and assessment of environmental noise, followed in 1984 by NZS 6803 relating to construction noise. However, it was not until the 1990s that a fuller suite of NZ specific acoustic related standards were developed and various international standards more widely adopted including ASTM sound insulation standards adopted into the building code. (See appendix E1 for a full list of the standards in use in NZ today, that are most relevant to residential noise control)

5.2.2.3 NOISE CONTROL ACT 1982

With the beginning of the move towards increasing housing density and greater use of electronic amplification for music, the first noise specific legislation was introduced - The Noise Control Act 1982 aimed to help deal with noise exceeding "reasonable levels", and methods for abatement (removal of nuisance) [14]. This was concerned with behaviour and controlling noise sources and noise perpetuators, rather than with the building's construction. Key features of this Act were later incorporated into the Resource Management Act 1991

5.2.2.4 BUILDING ACT 1991 AND THE BUILDING CODE

The first legislation incorporating national sound insulation building requirements for dwellings, was Clause G6 of the NZ Building Code, which was introduced as Schedule 1 of Building Regulations 1992, under the Building Act 1991 (part 6) and still in use today. This was the first NZ national building code which replaced the multiple building related rules across many former regulations and by-laws with a performance based regime [15]. Clause G6 of the NZ Building Code requires certain minimum performance criteria for attached dwellings, specifically the walls / floors / ceilings between abutting occupancies, and remains the core building regulation in relation to sound insulation to this day. (see section 5.2.5.1 and appendix D2.1 for more on G6).

Building Regulations 1992 was revoked as part of the reforms that produced the Building Act 2004, but its Schedule 1 "The Building Code", remains as a legislative instrument under the Building Act 2004.

5.2.2.5 RESOURCE MANAGEMENT ACT 1991

The Resource Management Act 1991(RMA) was introduced at the same time (and is still in use today) as the basis for current environment noise controls in NZ. These controls are primarily enacted through district plans and resource consents. These set appropriate zoning and noise limits, and requirements to avoid, remedy or mitigate the adverse effects of noise based on local conditions (including in some instances requirements for building façade performance, primarily in noisier residential locations)

The RMA replaced many of the then existing regulations covering town planning and resource management, including the Noise Control Act 1982. *"The Resource Management Act 1991 (RMA) is New Zealand's primary piece of legislation that sets out how we should manage our environment. It is based on the principle of sustainable management which involves considering effects our activities have on the environment now and in the future when making resource management decisions."* - http://www.mfe.govt.nz/rma/about-rma/introduction-rma, 18/4/17

5.2.2.6 NZ HOUSING CHANGES

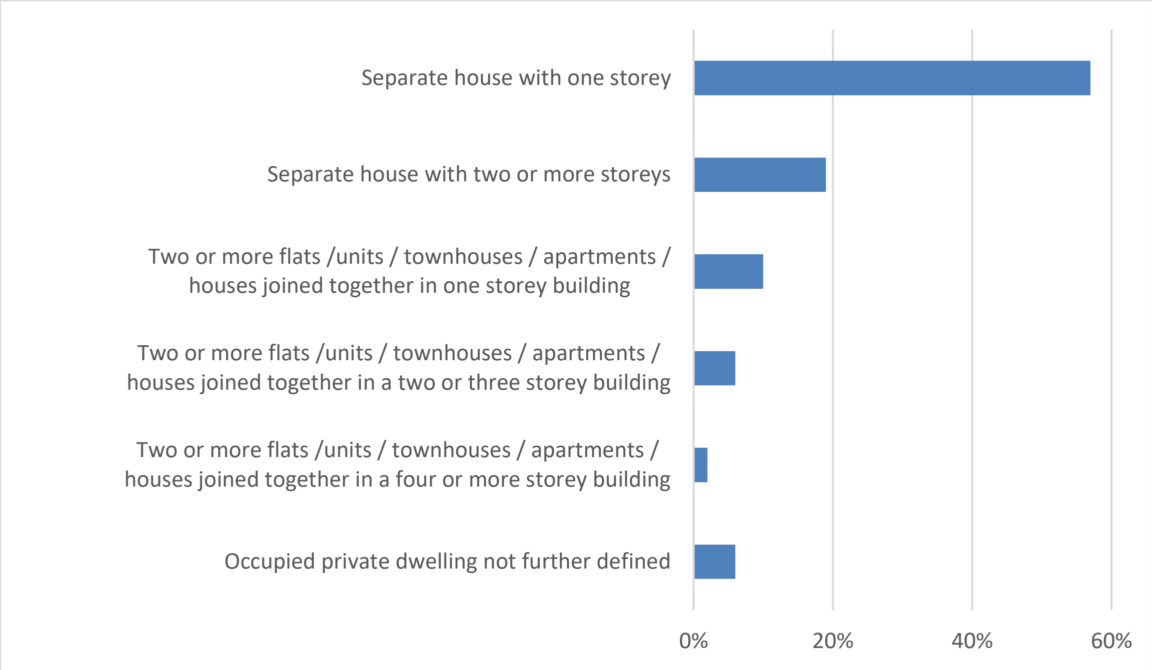
Traditionally NZ housing has focussed on detached, usually timber framed, dwellings on reasonably large sections, and there was only a low proportion of attached dwellings in the total NZ housing stock. With the kiwi "¼ acre dream" (the traditional aspiration towards a detached home on ¼ acre section), attached dwellings and apartments were often seen as lower status or temporary accommodation.

The Building Act and Resource Management Act were introduced in 1991, and alongside increasing urban populations and changing demographics, there were changes in the emphasis of the building industry. Apartment / townhouse building consents increased across NZ but especially in Auckland with a peak from the early to mid 2000s, known as the "apartment boom".

For a good graphic demonstrating the "apartment boom" across NZ, see Figure 5 on page 15 of [16], available at http://archive.stats.govt.nz/~/media/Statistics/browse-categories/people-and-communities/housing/auckland-housing-2013/housing-in-auckland-trends-1991-to-2013.pdf

More recently, the establishment of Auckland Council in 2010, has seen the development of a new Unitary Plan which is just becoming operational from 2016. This plan combines district and regional plan from the 7 former city councils and Auckland Regional Council which were amalgamated to form Auckland Council, responsible for NZ's largest city with approximately 1/3 of NZ's population. The unitary plan puts a much greater emphasis on increasing housing density with fewer restrictions up to 3 storeys in many more areas. The major Christchurch earthquakes in 2010 and 2011 have also contributed to major residential rebuilding projects.

Figure 4: Percentage of dwelling types for occupied dwelling types as recorded in the 2013 NZ Census.
Values as calculated in Volume 2, Chapter 2, Pg 564 of Cost action TU0901 [12].



Groups such as the government's Housing NZ Corporation, one of the country's largest residential developers, and many private developers and "design and build" companies are shifting their focus from the traditional 3-4 bedroom standalone house to more attached medium density housing (terraces, low level apartments) in a greater range of scales including 1-2 bedroom and 5 bedroom, to better cater to demographic changes.[http://www.hnzc.co.nz/assets/Uploads/Briefing-to-Incoming-Minister-Responsible-for-Housing-New-Zealand.pdf]

These developments are among the reasons for the establishment of the BRANZ MDH research programme begun in 2016 (Section 2.1), the output of which should be consulted for further information.

Building envelopes and even structure types for housing have changed considerably over time, with an expanded range and many new materials and techniques for partitions, cladding, roofing and windows/doors, and the incorporation of typical commercial building techniques such as curtain walls and composite flooring (steel tray & concrete). Engineered wood (e.g. cross-laminated timber CLT) is a recent addition to the structural materials available for use. The sound insulation performance of buildings using traditional and newer methods and materials needs to be well understood to ensure good outcomes.

As apparent from the 'leaky home' phenomenon for NZ housing built from the early 1990s to early 2000s, the introduction of new building materials and methods do not always go smoothly. These failures highlighted the need for full testing, practical robust resilient solutions, good training and anticipating issues ahead of time rather than reacting to poor outcomes later.

Geographical considerations

Earthquakes: NZ lies on the pacific ring of fire with most of the country prone to earthquakes, so designing buildings to withstand seismic events is a fundamental requirement. See www.seismicresilience.org.nz for more on building with good seismic resilient in NZ. Structures that work well for seismic needs tend to have more connections, which can have acoustic implications.

Temperature Climate: Having a temperate climate in NZ, temperature extremes are the exception for most of the country. Opening and closing windows has been a key part of ventilation and temperature control in NZ homes for much of the year – for example advice at www.energywise.govt.nz/at-home/ventilation. With densification, environmental noise levels tend to increase and having windows open for ventilation and cooling becomes less favourable. This means a corresponding increased need for active and passive HVAC systems that complement acoustic requirements. i.e. passive ventilation systems that are acoustically rated to keep out external noise, and active systems (mechanical heating, ventilation and air conditioning systems – HVAC) that don't themselves introduce unreasonable noise either through mechanical units or ducting.

Developments in sustainability to reduce energy use (usually featuring airtightness and good thermal insulation) need special care with regards to ventilation, and some thermal insulation is not helpful acoustically so active consideration must be given to integrating these features within the structure [12].

Timber industry prominence: In NZ, seismic requirements, material availability and cost (with NZ's strong timber industry) mean that timber has been a favoured building material for low rise buildings. The residential building industry is particularly familiar with and has labour skilled in light timber frame construction, which has traditionally been used in most detached housing. Developers/contractors therefore often favour light timber framing over heavier structures for attached dwellings under 4 storeys, as there are clear standards for timber frame design to this level (New Zealand Standard NZS 3604).

With less mass to impede sound transmission, extra care is needed with light timber frames to incorporate other techniques to reduce sound transmission in the building design, especially at lower frequencies. Many countries with higher housing densities have tended to work with heavier building materials (e.g. concrete, brick and stone), and have noted increasing issues with noise when introducing lighter weight constructions [12]. Information on building techniques that incorporate more mass in MDH buildings should also be widely available to allow informed decision making, rather than relying just on familiar techniques which might or might not offer the best or most cost-effective outcomes.

With a similar timber focus and seismic influence (on the American west coast), the Canadian National Research Council, specifically the department Institute for Research in Construction (NRC-IRC), has been a leader in the research of light timber frame construction and acoustics. Similarly, Scandinavian countries, also with large timber industries and use in residential housing, are key players on light timber frame research.

Wool industry: Sheep farming has been one of NZ's major industries since the 19th century, with wool carpet production really taking off in the mid twentieth century [pg 257 of [17]], along with later developments in synthetic fabrics. Wall to wall carpet became commonplace in NZ, and part of the housing aspiration, until recent trends towards harder flooring surfaces. For example, for NZ Building

Code Clause G6, the only "Acceptable Solution" offered for floors to meet impact requirements include carpet with underlay as part of the solution (it does not meet requirements without that carpet).

Although this has not been quantified, it has been noted in our consultation that the use of wall to wall carpets in homes is far more widespread in NZ than internationally, which has helped with reducing floor impact noise issues in NZ. Meeting impact noise requirements without soft floor coverings has therefore been more widely required internationally, resulting in a wider range of impact solutions and IT floor constructions available overseas for use with hard floor coverings (e.g. acoustic underlay, resilient layers, floating floor systems for overlay with wood, tile, concrete screeds).

Science and Technology

Evolving fields: The scientific fields of acoustics and noise control are still developing. Although considerable progress has been made in the second half of the twentieth century, the complexity of the fields mean there is still considerable work being done to improve things like sound transmission prediction and understanding people's subjective reaction to different noise levels / noise reduction.

Digital revolution: Acoustic measurements were traditionally done with analogue sound level meters and many manual calculations, with manual calculations the norm for acousticians well into the 1980s. With the introduction of powerful personal computers, and the miniaturisation and digitisation of much acoustic measurement equipment, the acoustician's toolbox suddenly expanded and in some ways simplified over the last 30 years. Powerful software for modelling and prediction is now possible on everyday computers, with rapid ongoing advancements in software functionality. Today's sound level meters are a core tool for all acoustic work and can automate many calculations, enabling calculation of things like sound insulation descriptors almost immediately. Today technology has leapt to the point that a sound level meter App in conjunction with the inbuilt microphone on your smartphone mean anyone can get a feel for sound levels (though not accurate enough for formal testing).

Sound Level Meter.
Photo: Tessa Phillips

Acoustic Modelling / Prediction Software: The development of acoustic modelling software is ongoing but as with all technical software or equipment, a certain level of expertise is required to ensure correct input and interpretation of results. For example, software for the modelling of the sound insulation performance of building elements (both for ISO and ASTM standards and using databases of common building component properties) are widely used by many acousticians and designers worldwide (e.g. INSUL developed in NZ, SonArchitect). However, they require a large instruction manual, explaining quite clearly the assumptions and standards used in generating the predictions, and good baseline acoustic understanding. Coupled with this are advances in auralisation which can be used to demonstrate predicted acoustic outcomes in a listening room or virtual reality setting.

Internet: The widespread adoption of the internet since the late 1990s has also changed the distribution of information. The expectation is to find plenty of information online, with further information only a click or two away. Manufacturer information can be kept up to date and it is in supplier's commercial interest to provide good quality information to potential customers. Due to funding limitations, the production of independent and generic information is not always as complete, though there is the expectation that impartial advice will be readily available on the web.

5.2.2.7 POSSIBLE IMPACT OF HISTORICAL DEVELOPMENT

Addressing environmental noise levels, including control of noise sources, was the first aspect to be formally addressed in NZ since these affected all housing types. Since the late 1970s, this area has undergone review and improvement especially with the introduction of the RMA and growing environmental awareness. Sound insulation and ventilation requirements to deal with excessive noise (e.g. from airports, ports, traffic corridors) are incorporated as part of district plan or resource conditions based on local conditions. However, the approach taken is not always consistent, with some regional differences as this is not handled at a national level

The low proportion and status of attached dwellings in NZ traditionally meant addressing inter-tenancy noise control was quite a low priority until recently, when that proportion and status has increased with more high-end MDH developments. Awareness has also been steadily increasing as greater numbers of people experience living in attached dwellings and the negative effects noise can have. Our survey respondents overwhelmingly thought that incorporating good noise control was very important for the long-term desirability of MDH (See Appendix G, Survey question Q18a)

MDH new skillset: For many NZ building industry participants in the residential housing field, who's primary focus and skillset has often been stand-alone timber frame housing, they are only beginning to be involved in medium or higher density projects and need to update their skills and knowledge to match (as noted by many of our survey participants). Therefore, although there is a general awareness that noise as an issue, understanding and implementing the solutions to reduce noise effects is somewhat in its infancy amongst the broader building industry.

Most countries with denser housing have been iteratively improving their inter-tenancy and façade requirements since the mid-20th century, when sound insulation descriptors were first established [18]. Their industry participants are more used to working on, and more systems geared towards multi-unit dwellings.

By contrast, formal building controls for inter-tenancy noise were only introduced 25 years ago in NZ (1992) and not really revised since. As attached dwellings become accepted as a long-term housing type, and the proportion of attached dwellings increase, the expectations for quality have also increased. Regulations need to ensure they continue to meet minimum health, safety and amenity expectations, so continuing assessment of end user needs is important as these can change.

Some survey respondents noted their concern that insufficient building code requirements regarding noise, and inadequate compliance with those requirements, have left NZ with a legacy of many poorly acoustically performing dwelling, though this has not been fully quantified at this time. Certainly noise has been highlighted as a leading source of complaint amongst NZ apartment dwellers and a leading cause for people moving from apartments (e.g. Wellington City Council survey [19]) but correlation between complaints and the actual building performance has rarely been investigated in NZ. I.e. were complaints primarily from older housing predating the building code, or ones where minimum performance criteria were not met in practice (e.g. are objective acoustic test results available?) or do even those meeting minimum requirements generate significant issues. Overseas research can give some guidance, but local conditions need to be assessed too, to match with local construction techniques and cultural expectations. This type of feedback is important for decisions on the minimum criteria needed in the building code or to understand market demand for higher performing solutions.

5.2.3 DRIVERS FOR ACOUSTICAL DESIGN

Our consultation sought to identify industry feelings on the key drivers for acoustical design in MDH in NZ with, as you might expect, the following two primary drivers

1) **Health, wellbeing and amenity**: A desire to provide residents with good acoustic comfort

2) **Cost**: Budget constraints limiting what can be achieved in practice

Efforts to improve sound insulation will usually involve some extra cost for additional materials and design advice. Without pressure, from within the project team and/or client requirements, projects tend to work to minimum regulatory requirements. These are the legal requirements, but there is also an understanding that these regulations should provide at least an adequate levels of performance.

3) **Regulations /Compliance**: Minimum Building Code and District Plan compliance requirements therefore become the third core driver.

Survey respondents' comments indicated that awareness is gradually increasing in NZ of the importance of providing good acoustic comfort, as more people live in denser housing areas, but that there is still a long way to go, with densification reasonably new to NZ. It was generally felt that understanding of how to deal with noise was still low, with differences in interpretation and implementation of code compliance also an issue leading to different outcomes, with much more information wanted across all areas.

> *"There would be an assumption that noise would be considered and that the minimum statutory requirements should achieve a good level of noise control" [OFFI, Q4]*

Driver for MDH desirability

When asked the effect of acoustic quality on the desirability of MDH (e.g. Survey Q18a), there was overwhelming feedback that good noise control is very important to positive long term outcomes for MDH. Comments included that for residents, when in their homes, it is what they hear that gives that sense of proximity to others. Though some might like to know there are others nearby, most appreciate quietness and privacy when within their own home. Noise can therefore be a fundamental difference in the experience of MDH versus stand-alone housing.

Surveys on apartment living often highlight noise as one of the key negatives of denser living (e.g. A 2009 Wellington City Council apartment survey rated noise as the least liked aspect of apartment living (27%) and was second only to lack of indoor and outdoor space as reasons for moving that related to the building [19].

Similarly, during the recent process in Victoria, Australia, for developing "Better Apartment Design Standards" (BADS), the 2015 consultation phase included a community survey, with current apartment dwellers specifying noise and lack of space as the biggest negatives of apartment living, with noise minimization number three in importance for effective apartment design only marginally behind the need for 1) natural light, 2) natural ventilation (good air quality), and well ahead of many other factors including amongst others more indoor space, energy efficiency, outdoor space, outlook, and car-parking (section 4.6 of [20], see https://www.planning.vic.gov.au/policy-and-strategy/planning-reform/better-apartments for more on the Victoria BADS process and outcomes)

Developer not End-User Driven

Unlike standalone housing, where end-users will often have an input into design, MDH is primarily developer driven, on spec. Therefore, **developers** and their agents are the key drivers of what is implemented in practice, with economic considerations a top priority. Industry feedback indicated designers often wanted to provide higher levels of sound insulation than required by regulatory minimum, but that acoustic considerations were not often given priority by developers.

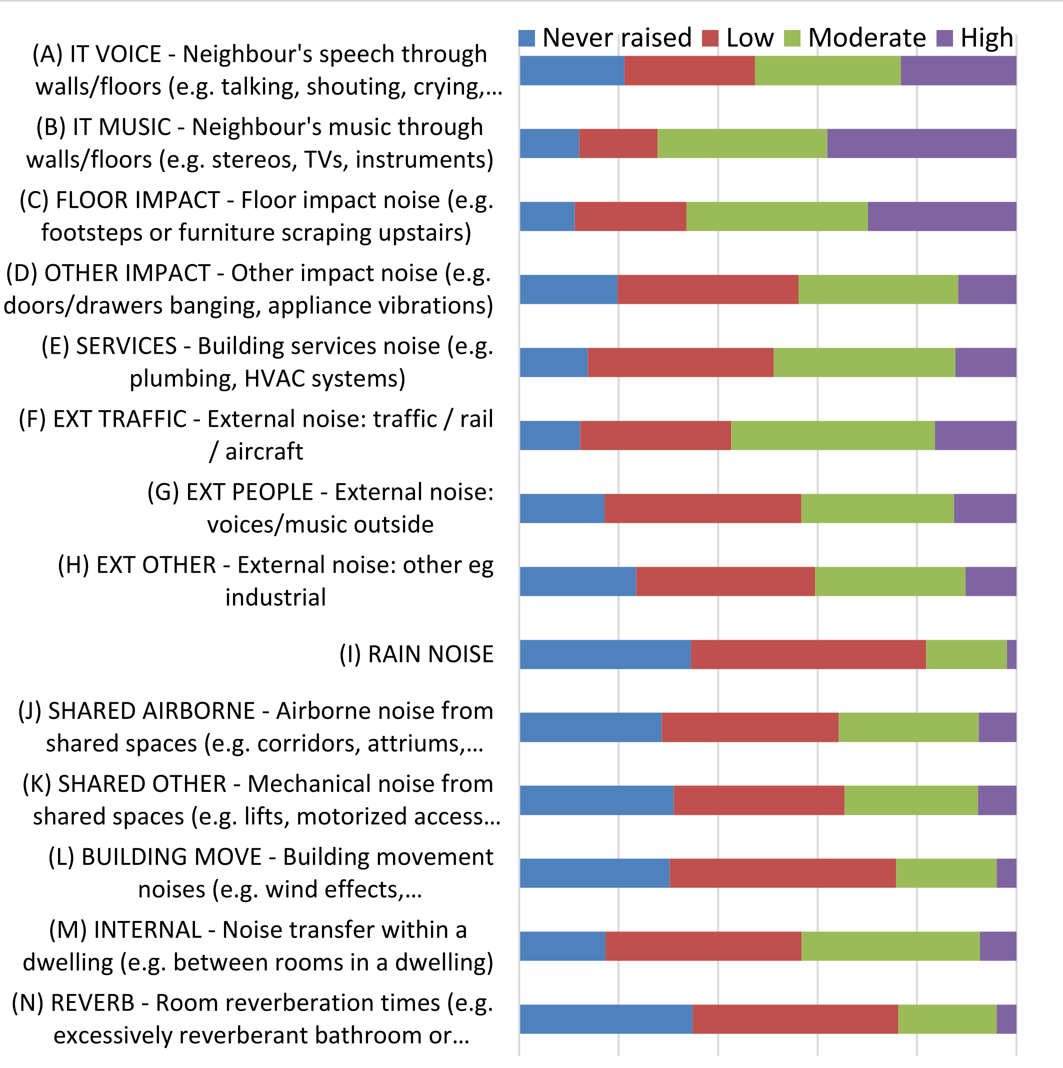
Unlike fire and structural requirements, acoustic considerations are non-life threatening and invisible so, as for many other sustainability and internal environmental aspects of building design, often take a back seat except where regulated for or actively pushed. It was frequently noted acoustics is among the first areas where costs are cut, so targeting developer awareness of benefits and reasons for good acoustic design was seen as hugely beneficial. Some developers, especially for mid-high range MDH do aim well above code minimum and market this as a point of difference, but respondents noted that plenty of higher end MDH work to minimum building code standards and may not live up to expectations acoustically. [see especially Survey Q4, 5, 18c, 18f].

Cost considerations raised most often in feedback were that building margins have to be very tightly controlled to be economically viable. A core issue for increasing acoustic quality is the high cost of building materials generally in NZ, especially those that are especially acoustically rated (with manufacturers noting that development of such materials, including testing etc. is costly). [Survey Q18e]. The cost and availability of professional advice both for design and proving compliance were also noted, though there was also plenty of examples of early and close integration of design areas enabling more cost-effective outcomes.

5.2.4 KEY AREAS INFLUENCING INTERNAL ACOUSTIC QUALITY

Key areas that need to be addressed to provide good acoustic quality in a dwelling include the following:

Figure 5: "Towards Quiet Housing" Survey Question 6 - Based on your experience, please rate the relative level of concern from end users for each of these noise sources. Responses shown proportionally for each source (approximately 520 responses for each source)
– This question aimed to gauge industry perceptions of the relative importance of noise sources to deal with through building design rather than an absolute measure.



- Neighbour noise: Inter-tenancy (IT) wall/floor design to reduce noise received by a dwelling from neighbouring occupancies (residential or other such as office/shop) and shared spaces / services (eg halls, stairs, lifts). This includes airborne and impact noise sources and is partially addressed by NZ Building Code Clause G6 as below.
- External noise: reducing noise from external sources through the building envelope design (façade, roof) – not covered in the NZ building code, but in noisy zones some aspects may be regulated within district plan / resource consent requirements (eg façade and ventilation requirement with windows closed)
- Building Services noise: minimizing noise from services such as plumbing, HVAC, lifts, mechanical doors, garbage chutes– not currently regulated for in NZ
- Internal noise: within a dwelling including sound transmission (e.g. between bedrooms and other rooms) and reverberation times – not currently regulated for in NZ, usually less of an issue than the above factors as these are more directly controllable by the occupant, but still worth consideration.
- Professional advice: Given the many factors that affect sound insulation (section 4.4), outcomes will generally be improved by professional advice to ensure all aspects have been considered and addressed adequately
- Building Siting / Layout: Planners and Urban designers need to consider acoustics when considering zoning and land use, and architects should consider acoustics when designing the building layout on site and arrangement of rooms.
- Detailing and Workmanship: Even with a good design, without sufficient detailing and good workmanship the final construction may not provide the designed outcomes.
- Economic: There needs to be cost effective construction materials and systems that can be used to provide good noise control, and sufficient incentive or regulation to ensure added costs will be accounted for as part of providing quality housing – clear cost-benefit.

The following section details current noise related regulations in NZ. Acoustical design cannot be considered in isolation of other design aspects, with the section 5.2.6 outlining other areas which must be balanced with acoustic requirements. Appendix D covers each of these areas in considerably more detail in the NZ context.

5.2.5 CURRENT NOISE RELATED REGULATIONS

This section outlines the key current regulations relating to noise in NZ, the Building and Resource Management Acts, and a brief comparison with international codes. More in-depth information on G6 and district plan requirements are covered in Appendix D2

5.2.5.1 BUILDING ACT 2004

The core regulation relating to sound insulation for attached dwellings is Clause G6 "airborne and impact sound" of the NZ Building Code (found as Schedule 1 of the Building Act 1992 [21]). This sets the relevant performance standards for new building work under the Building Act 2004.

Building Code Information

The Ministry of Business, Innovation and Employment (MBIE) is currently responsible for looking after the building code, having taken over this role from the former Department of Building and Housing in 2012. MBIE's Building Performance website site www.building.govt.nz provides core information and handbooks on building code compliance as well as information on "determinations" (legal clarifications that help with interpreting code requirements). Acts of parliament are available at www.legislation.govt.nz

NZ Building Code clauses are broken down into 3 levels of requirements: 1) Objective, 2) Functional Requirements and 3) Performance. Supporting Compliance Documents are provided for each clause outlining definitions, references as well as optional “Acceptable Solutions” and “Verification Methods” which if used demonstrate compliance with the Clause and must be accepted by Building Consent Authorities that process building consent applications and sign off finished constructions.

What G6 covers and doesn’t cover

Given its importance, Clause G6 is repeated in full here.

Clause G6—Airborne and impact sound

Provisions

Objective

G6.1

The objective of this provision is to safeguard people from illness or loss of *amenity* as a result of undue noise being transmitted between abutting occupancies.

Functional requirement

G6.2

Building elements which are common between occupancies, shall be constructed to prevent undue noise transmission from other occupancies or common spaces, to the *habitable spaces* of *household units*.

Performance

G6.3.1

The *Sound Transmission Class* of walls, floors and ceilings, shall be no less than 55.

G6.3.2

The *Impact Insulation Class* of floors shall be no less than 55.

G6 utilises the ASTM standards Sound Transmission Class (STC) and Impact Insulation class (IIC) which are forms of sound insulation descriptors (as discussed in section 4.4). The companion “Verification Method” specifies one option for compliance as “Field test results shall be within 5dB of the performance requirement”. Various ‘determinations’ have confirmed interpretation of some aspects of the code, in terms of what areas are included or excluded.

In basic terms G6 requires

- Airborne sound insulation performance of no less than STC 55 (field measurement no less than 50) must be achieved by common walls and common floor/ceiling assemblies between any room of an occupancy and habitable spaces of a separate household unit
- Impact sound insulation performance of .no less than IIC 55 (field measurement no less than IIC 50) must be achieved by common floor/ceiling assemblies between any room of an occupancy and a habitable space of a vertically separate household unit
- Multi-unit dwellings where there are no shared habitable spaces, regardless of unit title arrangement, are required to comply with the Building Code Clause G6 (e.g. self contained

apartments in retirement complexes, but not hostels with shared facilities [Determination 2012/070, 2015/04]

- Apartment doors are not required to comply with the Building Code Clause G6 [Determination 2015/04]
- Horizontal transmitted impact sound and diagonally vertically transmitted impact sound across an inter-tenancy wall is not required to comply with the Building Code Clause G6 [Determination 2015/07]
- Diagonally vertical tests from one apartment directly to another from a bathroom to a living room or a deck to a bedroom are required to comply with the Building Code Clause G6.

G6 Compliance

Although some noted that the NZ building code Clause G6 is nice and simple, this simplicity comes at a cost in terms of being fairly open to different interpretations.

There is confusion around the need for testing as well as the areas that are covered by the performance requirements. This lack of clarity results in significant differences in how the clause is interpreted by Building consent authorities and consultants around the country, as noted in MBIE Determination 2015/04 re building elements between occupancies and common spaces.

In some areas G6 compliance is checked simply by confirming the product information for an IT wall / floor meets the listed STC/IIC requirements, in others a broader approach is taken to acknowledge the effects of workmanship and flanking - for example Auckland Council practice is to get sign off of the design (PS1) and on completion production of a PS4, confirming construction inspections and on-site tests for a samples of units with inter-tenancy floors [22]. (PS1 and PS4 are Producer statements, see Building code handbook for more [23])

There are many areas where the requirements of the code are still unclear including: temporary accommodation, decks, walkways, refurbishments and enclosed carparks.

The lack of clear design standards causes inefficiencies in the design and introduces a high level of risk to territorial authorities as well as designers and builders. A simple document provided by MBIE providing a clear 'interpretation' of the code would be a big step forward for the acoustic design of multi-storey dwellings. In our opinion this should be one of the first documents referenced as part of our suggested Quiet Housing Hub (see section 6.1.1 for more on this suggested resource).

When aiming for G6 minimum requirements, there is more incentive to get the design and construction correct where there are consequences if acoustic tests fail. Where a tick the box approach occurs there is less guarantee that the elements, even if they meet the standard in the lab, are performing to a suitable level in situ. A standardised approach to testing would improve standards and provide greater cost certainty.

Clause G6 Proposed changes

Clause G6 was added when the code was first implemented in 1992, and apart from very minor amendments to the compliance document in 1995 no changes have been made since.

There have been efforts since the early 2000s to update the code clause and supporting compliance documentation [5]. The impetus for change has come from those in industry who feel the minimum levels and areas covered in the code do not provide sufficient levels of health and amenity for end-users, but also to help clarify some areas open to interpretation in the existing code.

Clause G6 and its Compliance Document have been actively under review for over 15 years, but successive proposed changes have been rolled over, with the last round open to public submissions in 2010 [24]. The latest update proposal document that was expected to go out for public consultation in

2016 is still to be released (though the research team has had some limited access to the document through MBIE). As this project comes to an end it seems unlikely the draft will appear until well after the next election as the draft has not been approved for public consultation. Key areas proposed for change over this time have been:

- A general title change to “protection from noise”
- increasing the minimum sound insulation standards to higher performance levels for impact and airborne noise, with possibly additional protection between dwellings and other types of occupancies (e.g. shops below)
- mandating criteria for certain areas not currently addressed (e.g. plumbing and mechanical services noise) or not clearly addressed (e.g.noise transfer from common spaces such as corridors, foyers, carparks),
- changing to more internationally recognised standards (ISO),
- change to whole system rather than building element performance metrics, to ensure flanking transmission is incorporated in designs, with metrics which can include some lower frequencies.
- providing consistency for façade sound insulation / ventilation requirements to deal with environmental noise -rather than leaving these to be locally mandated in district plans in different ways (though with reference to the district plan for external noise levels). This would also provide a clearer compliance path for building work through the building consent process
- providing a greater range of Acceptable Solutions (especially floors without carpet) and verification methods (including testing)

Some feedback on past proposals also indicated a desire to include requirements for schools, motels/hotels, healthcare facilities and other forms of buildings, and this was also raised in our consultations.

Since 1992, there are many factors that have potentially impacted requirements for sound insulation, such as;

- Developments in entertainment system (e.g. home theatre and gaming) have changed the nature and volume of noise generated within apartments, especially low frequency / bass components, with an accompanying expectation of being able to enjoy these entertainments in the home without having to worry about annoying neighbours,
- Introduction of the internet (in the mid 1990s) and broadband connections mean there are more options for working from home,
- A move towards many more large developments of multi-unit dwellings, including large retirement village apartment complexes, and increasing traffic and population density increasing urban background noise levels.
- Trends towards more hard surfaces in homes, with higher reverberation times (and consequently more source room ‘loudness’) and more floor impact noise issues, which can potentially affect neighbours;
- Changing trends in construction methods, materials and solutions available – e.g. increasing use of light timber inter-tenancy floor construction, or composite floors with thinner concrete /steel tray construction. Some countries note special conditions or higher criteria for light weight construction or incorporate correction terms to descriptors for low frequency noise to address this.
- changes in the standards in use

- the current G6 refers to ASTM standards for which significant developments have occurred in the last 25 years in relation to field measurements, which are not well reflected in the current G6 and compliance document wording. Notably, the addition to the ASTC (apparent STC) which include flanking, as opposed to field measures of element performance (FSTC) with flanking paths supressed. In practice ASTC measures are usually used for testing in NZ.
- A shift internationally towards using standards for on-site measurements or predictions for the performance of the whole system (better incorporating flanking effects) rather than individual building elements, in building regulations.
- Our nearest major neighbours, including Australia, use ISO standards, with increasingly wider use of ISO standards internationally - even North American documentation is increasingly incorporating ISO standard information alongside ASTM information

Survey feedback on G6 (especially Survey Question 7 but also comments throughout)

Note that during our consultation their seemed to be range of opinions fairly evenly spread on the spectrum between

- Those for whom stronger regulation was seen as unnecessary since the current minimum requirements were thought to be adequate for most end-users. It was thought more important to have the choice to improve performance with market forces driving uptake, especially since acoustics is such a subjective area.
- Those who thought that current minimum performance level are too low to achieve satisfactory acoustic comfort for most end users. Higher performance criteria were wanted in regulations especially since for lower budget projects where minimum regulations are most likely to be used.

This indicates the lack of clarity around the success or otherwise of the current building code performance criteria. Those in industry also noted rarely hearing from end-users directly – especially in MDH developments (Survey Q5). The exact purpose of the code was also raised – what level of amenity is it aiming to achieve – 60%, 80%, 90% not regularly annoyed by noise? There are costs associated with meeting higher performance criteria, so understanding the broader benefits and actual end-user needs is important for industry buy-in for a change.

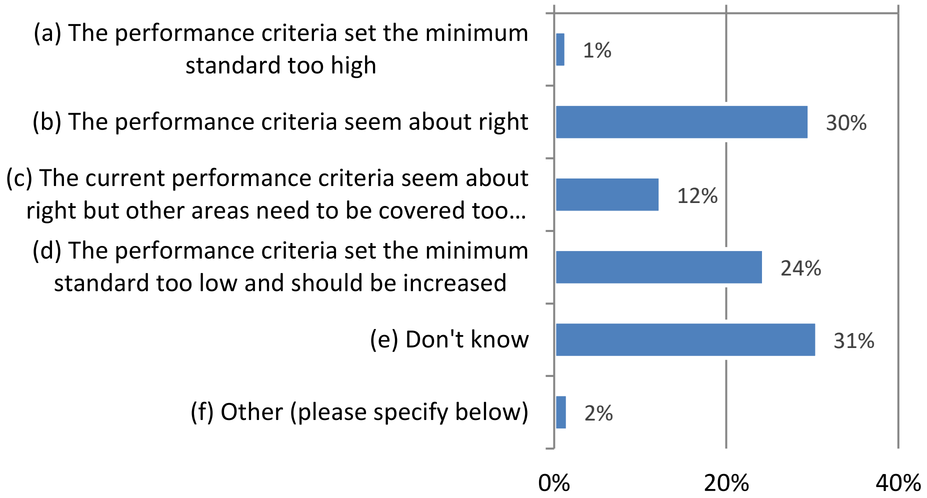
Clarity around compliance was also noted as required to ensure the same minimum standards are being achieved across the country, rather than differing depending on the consent authority and acoustic awareness of consenting officers / inspectors.

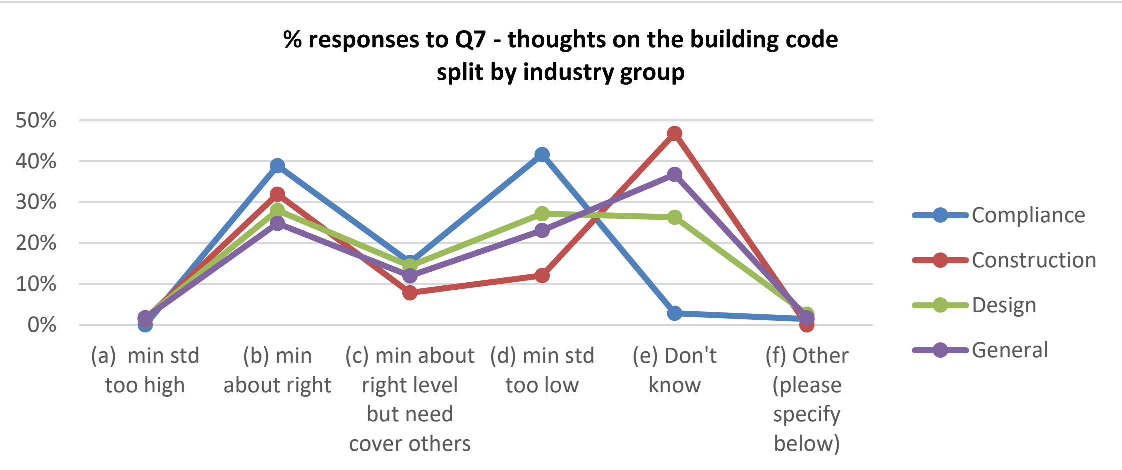
Our survey indicated that although there is some diversity of opinions around how to change the code, of those that offered an opinion over 55% were keen to see some kind of increase in the standards required (either through covering additional areas and/or higher minimum performance criteria for inter-tenancy sound insulation). Less than 2% felt the current standards are too high.

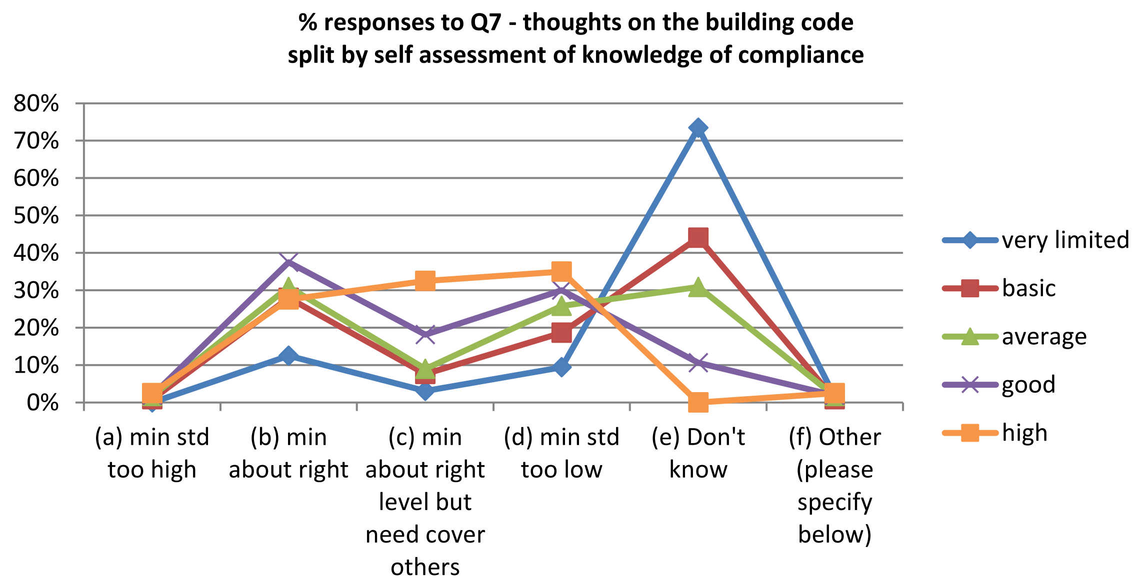
Figure 6 show the overall quantitative response to Q7, plus broken down by industry grouping and by self-assessed understanding of compliance. As you'd expect those in compliance (building officials) and design, or with higher self assessed acoustic compliance knowledge were most likely to have an opinion. The pattern of spread between answers (a) to (d) was fairly similar in all cases – except for those who rated their knowledge of compliance highly who were keener on regulatory change than others, and those in construction were most likely to think the code is ok as is.

See Appendix G Survey analysis on Question 7 for a full breakdown of feedback, and Appendix H for actual feedback comments.

Figure 6: ***Question 7: What do you think about the NZ Building Code Clause G6, which relates to sound insulation / transmission between "abutting occupancies"?*** **Response as % of 566 total responses, then graphed showing the split by industry group and knowledge of compliance (self assessed in Q3)**







Given that over 20 years all previous attempts at amending the code have failed, it might be worth considering whether additional NZ specific information (eg post-occupancy feedback linked to construction performance) needs to be presented in support of the recommendations to better support the need for change. A fuller review of why changes are not going through might also be beneficial - is this due to lack of evidence to promote the change and demonstrate sufficient cost benefit? Low priority? Politics around anything that might impact affordable housing? Are drafts too complex, impractical, trying to cover too much? Is the split between what is in the code and what in the compliance document appropriate?

Perhaps there needs to be a phased approach to changing the code. One way would be providing guidance documents with plenty of information on the cost benefits, good / better /best solutions that demonstrate how incremental cost changes can significantly improve performance, best practice guides that although not yet mandated specify the types of additional criteria that can be beneficial to address along with supporting research to aid these needs. Along with an awareness raising campaign, this should help prime people and better inform/support changes to the code down the track, especially since the proposed Clause G6 changes are significant.

Providing guidance and better information immediately is preferable to waiting on the hope of regulatory change which may or may not occur for some time.

5.2.5.2 RESOURCE MANAGEMENT ACT 1991 (RMA)

The RMA provides provision for local government (eg regional, city and district councils and) to address excessive noise (and vibration), including long term planning efforts and managing noise complaints. (RMA 1991, Clauses 16, 326-328).

In noisy zones, sound insulation and ventilation requirements are often specified in district plans. Façade sound insulation requirements usually take one of two approach 1) specifying a required average noise level inside and designing the façade to achieve this based on average environmental noise levels or 2) requiring the façade to achieve a specific sound insulation performance level. Currently environmental noise regulations are developed separately for each district/unitary plan. Many different approaches are taken in different geographic areas, including different noise limits and metrics used, and the methods used to set zoning, designations, overlays etc. for different noise sources, with compliance also confirmed in different ways by different authorities.

See Appendix D2.4 for more in-depth discussion on external noise requirements and Appendix D3.3 for more on meeting ventilation and HVAC requirements .

The Ministry for the Environment (MfE) can also help provide national guidance in relation to meeting RMA needs, such as national level planning instruments. The diversity of district plan types and structures has been noted as a barrier to the implementation and consistency of district plans [25]. Currently there is a project looking to develop national planning templates for district plans that could allow for more consistent approaches to their development, as well as further National Planning Standards [26]. Setting up a consistent framework for handling environmental noise within district plans is potentially on the cards as part of this – though specific local noise sources (e.g. airports, ports, industrial, quarry, traffic corridors road / rail) would still need to be addressed on a site specific basis.

As noted in the previous subsection, there are efforts as part of updates to Building Code Clause G6 to incorporate façade/ventilation requirements within the building code as part of addressing environmental noise (with reference to the noise limits in district plans). During our research, there seemed to be some differences of opinion about what inclusion of these areas into the building code would have on existing and future requirements under the RMA. Some thought the Building code requirements would overwrite all existing sound insulation / ventilation requirements in district/unitary plans which could no longer apply, others that it would offer a minimum standard with higher requirements allowable within district plans to meet specific situational needs. Attempts at gaining a clearer legal picture are underway but have not been completed at the time of finishing this report.

5.2.5.3 COMPARISON WITH OVERSEAS REGULATIONS IN USE

- **Europe:** The COST Action TU0901 project demonstrated the diversity of regulations in Europe. Comparison is not always straight forward since the sound insulation descriptors used calculate performance in different ways and are not always directly translatable, though all use descriptors defined though ISO standard 717 (which was first introduced in 1968).
  Efforts such as [27] to compare our minimum standards with those in Europe have tended to put us towards the lower end performance wise, whereas the Cost Action Tu0901 comparison assesses our minimum impact and airborne requirements in a similar broad band to most European standards when compared to their proposed classification scheme (Class D, figure 5.2, volume 1 of [12]). However, we don't have building services or façade requirements that are more common there, or requirements for internal non-inter-tenancy walls or reverberation requirements in common spaces that are also sometimes specified.
  Many European countries have changed to requiring assessment of whole building performance at the design stage and mandatory testing of a sample of units, and/or strict construction monitoring (e.g. UK 2003, France 2014). This follows issues identified with performance when compliance was based purely on the listed performance or design signoff based of individual building elements, with no follow up at the construction stage.

Closer to home, other English speaking countries on the pacific rim, such as the US, Canada and Australia tend to use a model building code type structure with a national building code which can be used or modified at regional level. The North Americans use the same STC/IIC standards as here, but minimum requirements are lower than in N.Z

- **USA –** the model building code used in the US is the US based International Building Code (IBC). Section 1207 of the IBC specifies standards of minimum STC 50 for "common interior walls, partitions and floor/ceiling assemblies" and IIC 50 for floor/ceiling assemblies separating dwellings, with a 5 point allowance for field measurements, ie field tested minimum STC/IIC 45. However the guidance documents associated with this ([28] available at http://media.iccsafe.org/store/2015Handbook/ICC_G2-2010.pdf) specify this a health and safety minimum and will not necessarily provide adequate level for widespread occupant satisfaction, (with large percentage highly annoyed). They recommend STC/IIC 55 as an acceptable level and STC/IIC60 as the preferred level. Some state codes also regulate for higher minimum standards than STC/IIC 50.

- **Canada** –The National Building Code (NBC) of Canada previously specified a minimum of STC 50 for separating partitions, with a recommendation to design to at least STC 55. However the 2015 update changed the focus from element performance (STC of the common wall/floor) to whole system performance between two spaces. It includes a change with compliance now requiring to demonstration that flanking paths have been addressed in designs, meeting performance of ASTC (apparent STC)> 47 either by testing or design certification. There is no regulated requirements for impact noise. Additional information on predicting flanking effects have been made available in Canada to support these changes. http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/codes_centre/technical_changes_2015.html, and https://www.researchgate.net/publication/283548737_Change_in_Canada%27s_National_Building_Code_-_Part_1_Overview_of_New_Requirements_and_of_Projects_Supporting_the_Change

- **Australia –** Building Code Australia requires slightly different requirement for standalone & row housing (BCA volume 1) to multi-unit dwellings/apartments and aged care buildings (BCA volume 2). Regulations apply to inter-tenancy walls and floors and they use ISO standards. The basic requirement is to use separating elements rated R_w+C_{tr} >=50 for airborne noise (walls and floors) and $L_{n,w}$ <62 for floor impact noise or field verification through measurements/predictions of $D_{nT,w}$+C_{tr}>=45 for airborne noise through walls/floors, and $L_{nT,w}$<=62 for floor impact noise. These values are harder to directly compare with NZ, since the low frequency correction term C_{tr} can be significant for lighter weight constructions, even though R_w is often similar to STC. $L_{n,w}$ generally approximates to 110-IIC so slightly lower minimum standard for impact noise to NZ.

Within the scope of the project we could not do a full comparison with other Pacific rim countries with similar seismic needs but this is probably worth further investigation.

All the regulations internationally are evolving with ongoing debate and research around subjective versus objective measures and what level to set as a minimum, but local expectations and constructions must be part of the debate – see Appendix E3.4

5.2.5.4 NOISE CONTROL FOR OTHER FORMS OF BUILDINGS

Although family homes are the primary form of housing, aged-care, shared and temporary accommodations also provide shelter to many. G6 only covers inter-tenancy protection for household units in abutting occupancies (eg common elements between apartments, or between an apartment and other occupancy such as shop or office)

Since the 1980s, when the first major retirement villages began in NZ, and with NZ's aging population, apartments have grown to become an important part of many retirement village complexes. http://docs.business.auckland.ac.nz/Doc/Working-Paper-1-07-PensionDiscussion-The-changing-face-of-the-Aged-Care-Sector-in-New-Zealand.pdf Recent MBIE determinations have confirmed that those with self-contained apartments must meet the inter-tenancy noise requirements of NZBC G6 which covers abutting dwellings, though rooms in residential homes and medical facilities with shared facilities do not.

Note also that hotels and motels are currently not required to meet G6 (though there is some debate on this interpretation), though many aim to meet or exceed similar standards in order to meet customer needs and reduce complaints.

Schools, commercial offices and workplaces are outside the scope of this project. However, it should be noted that although there are no building code requirements regarding noise control for these activities, there are a number of standards which can be utilized when planning these types of spaces e.g.

- NZS 2107 Acoustics - Recommended design sound levels and reverberation times for building interiors [11].
- The Ministry of Education (MoE) - Designing quality learning spaces (DQLS) Acoustics Guidelines [29] became mandatory in 2017 for MoE schools. This document includes acoustic fundamentals, importance of acoustics for communications and how to address acoustics in learning spaces, standard details for wall and floor/ceiling constructions meeting different criteria, information on windows, doors.
- Occupational noise is the responsibility of the government agency WorkSafe NZ addressed through the Health and Safety at Work Act 2015 with NZ standard AS/NZS 1269 Occupational noise management another core resource. [30]provides a full overview of occupational noise requirements, also available at www.acoustics.org.nz/journal/pdfs/Hannah_L_ANZ2016.pdf

5.2.6 INTEGRATED DESIGN

Acoustical design cannot be considered in isolation; it is important to understand the overlap with other relevant areas of design. Whatever ideal design criteria are chosen, the overall design must provide at least the minimum performance criteria required in the New Zealand Building Code (NZBC) in each area. District / Unitary Plan and resource consents may also include additional mandatory requirements that must be met. The following is a list of the areas that most significantly require an integrated approach, with the relevant NZBC Clause in brackets

- **Structure** (Clause B1) including structural stability and seismic resilience and consideration of (Clause B2) Durability
- **Fire protection** (Clauses C1-C6) Acoustics and fire are often considered together in product information as there is a similar requirement to isolate a dwelling from its surroundings with minimal air gaps etc.
- **Ventilation / Thermal comfort*** - NZBC Ventilation clause (Clause G4) as well as district plan / resource consent requirements for ventilation, air quality, thermal comfort and moisture control, especially where windows may need to be closed because of a noisy or poor air quality external environment. Active and passive systems for heating, ventilation, air filtering, cooling and humidity control need to consider noise effects. (Passive ventilation is a natural ventilation system that makes use of natural forces, such as wind and thermal buoyancy, to circulate air to and from an indoor space, active systems are mechanically based). These ventilation systems work bring fresh air in and send stale air out as well as help to regulate the internal air temperature, but need to this while not themselves introducing or allowing entry of excessive noise
- **Natural Light** (Clause G7), influences window sizes, with windows a key factor in external noise control
- **Energy Efficiency** (Clause H1) Ensuring energy efficiency features such as glazing, insulation, thermal requirements are compatible with acoustic requirements.
- **Internal Moisture** (Clause E3) Fire/acoustic/thermal control needs tends to reduce airpaths, (ie natural ventilation), hence the need for balanced consideration of good ventilation, temperature and thermal resistance to avoid fungal growth and building damage
- **External Moisture** (Clause E2) Balancing water-tightness features in the exterior envelope with external noise control and flanking noise minimization.

*Note: the building code doesn’t specifically refer to meeting minimum temperature requirements for thermal comfort (Internal environment G5 doesn’t apply to general housing) or to managing excess heat (eg overheating of well insulated dwelling from natural light and occupants) but achieving a suitable internal temperature range should be considered as part of HVAC considerations. Maintaining temperature is addressed in part by thermal resistance requirements within Clause H1- Energy efficiency, but there is no control of temperatures.

Appendix D3 covers the interaction between acoustics and each of these areas in more detail.

Information Gap

This is an area where industry survey feedback indicated there is significant gap (e.g. survey Q11 – see Figure 7 in section 5.2.8.5). There is a desire for much more information on whole building construction options and designs, or systems that can address multiple design requirements at once, or a least better information on integrating the many different requirements rather than effectively having to do custom designs for all new builds. Construction systems meeting fire and acoustic requirements are often grouped together, given they both work toward reasonably airtight, isolated dwellings, but combining this with the connectedness of structural requirements takes careful attention, with environment considerations re energy efficiency (thermal) and air quality adding to the number of factors to be actively balanced.

Overseas there is much more mass production and modular housing as this tends to be more cost effective but tends to requires large scale developments whereas in NZ our detached housing history has tended towards more custom design and unique dwellings (rather than rows of identical houses).

5.2.7 CLASSIFICATION / RATING SYSTEMS

Building regulations tend to focus on specifying minimum performance levels that buildings must reach to meet basic health, safety and amenity requirements. However, this does not provide information on the relative performance above that minimum requirement. Noise is a form of environmental pollution and as such its consideration is also part of wider considerations of environmental effects (including sustainability) and associated efforts to improve buildings with these considerations in mind.

This is where the use of 'classification' or consumer 'rating' system comes in. For example, "good / better / best" or star / grade ratings. These can offer a quick independent measure of the level of performance, just as you have energy stars rating performance for appliances to help with comparison of products.

This is useful from a consumer perspective for better informed decision making, while also allowing recognition for work at levels above mandatory minimum requirements. They can provide an incentive to work to higher standards.

COST Action Tu0901 [12], Volume 1, Chapter 5, highlights the range of acoustic "classification" schemes used in Europe and also looks at efforts to define a European or international classification scheme using "Classes" A (best) to F (worst). Most minimum regulations internationally sit around Grade D in terms of performance in that scheme, including NZ, but at present there is no internationally adopted scheme.

There is currently no NZ based acoustic rating scheme, although there is an Australian based scheme that some survey respondents were aware of

- **AAAC Rating:** Association of Australasian Acoustical Consultants (AAAC) provides an Australian based Apartment and Townhouse Acoustic Rating system which is a star based system for various aspects of airborne and impact sound, building services noise, and external noise intrusion [31] (www.aaac.org.au/Guidelines-&-Downloads)

The only NZ housing rating system incorporating components related to residential acoustics that we identified was:

- **HomeStar:** The NZ Green Building Council (NZGBC) run the HomeStar rating system which rates a range of environmental features. For version 3.2 this includes 2 points out of 105 for noise control, in the "Energy, Health and Comfort" category EHC-9 "Sound Insulation", so only a very small component. Note the NZGBC also run the NZ Green Star tool for Commercial buildings.

Other residential rating systems not currently incorporating residential acoustics include

- **Lifemark** – NZ residential rating system but no acoustic component,
- **NABERS** (National Australian Built Environment Rating System) – currently includes ratings for energy efficiency, water usage, water management and indoor environment (IE) quality. The Indoor Environment (IE) tool, which includes acoustic comfort, only currently applies to commercial buildings and the NABERS NZ rating only currently applies for energy efficiency in commercial buildings.

Even if there is no rating system in use, industry survey respondents were keen to have a better understanding of what different levels of performance mean in practice (i.e. how different does STC 58 seem than STC 55, is it worth aiming for STC 63 and how much is this likely to improve satisfaction levels?). There was a desire for independent information on best practice for difference performance levels, as well as independent information / reviews of commonly used constructions in NZ.

5.2.8 INFORMATION SOURCES NZ AND INTERNATIONALLY

5.2.8.1 SOURCES USED BY INDUSTRY

With the specialised nature of acoustics, our survey indicated that most in the NZ industry did not rely on paper based information, but (except for acousticians) sourced acoustic information primarily from

- online resources (predominantly from Product suppliers/manufacturers and MBIE, but also Councils and BRANZ and google searches),
- professional advice
- information within their organisation and from peers.

Printable online resources and face-to-face training were the preferred source of additional information (See appendix G – Survey Questions 10, 10A, 16).

Interestingly, although sites that provided information on regulations were frequently referred to (e.g. MBIE, councils), they did not rank highly in terms of usefulness (beyond listing legal requirements). The sources people found most useful tended to be documentation associated with proprietary products (e.g. product manuals).

This is understandable given the need for detailed implementation of systems but people commented frequently on wanting more independent information and guidance to be available, as there is always an element of concern of bias even for the generic information provided within supplier resources. Professional advice, then information provided by BRANZ (publication articles, appraisals etc) were seen to be the next most helpful.

What people seemed to like about proprietary information was that they provide a good level of supporting information and details which are directly usable. There seemed to be a strong desire for the availability of prescriptive solutions. Those drawing up initial plans cannot know the intricacies of all the different fields, they are keen to have a place to start, constructions that usually work, even if project specific details are then modified through professional advice in each area. Ensuring the final plans include sufficient detailing is essential for the construction phase so getting details right is critical to good outcomes.

Given the high frequency with which survey participants noted sourcing information from within their own organisation or from peers (survey Q10), it highlights that even just increasing the knowledge of a few can help spread knowledge and to help increase baseline understanding across the industry. Perhaps there is a role for social media / forums, or online knowledge sharing sites – especially given the relatively small scale of the NZ building industry?

Appendix E gives a fuller run down of examples of resources available.

5.2.8.2 INDEPENDENT SOURCES IN NZ

Key Independent online sources of residential acoustic information in NZ include

- **Listed regulatory requirements** – NZ Building code clause G6 [21], The relevant noise sections of district plans (e.g. "Section E25 Noise and vibration" of the Auckland Unitary Plan – see https://www.aucklandcouncil.govt.nz/ for the latest version)
- **Supporting compliance documentation** – e.g.
  - The Building Code Handbook [23]
  - Clause G6 Compliance document [5] and MBIE guidance, www.building.govt.nz/building-code-compliance/g-services-and-facilities/g6-airborne-and-impact-sound),
  - guidance documents provided by councils to support their district plan requirements or role as Building Consent Authorities (for example Auckland Council practice notes such as "AC2206: G6 Airborne and Impact Noise" and "AC2210: Alternative Solutions")
- **General guidance pages** within housing design or planning sites – usually a few pages summary of things to consider (e.g. www.smarterhomes.org.nz, www.level.org.nz, CCANZ apartment design guide [32])
- **Other:** miscellaneous articles in journals, magazines or general building websites. Independent appraisals of product code compliance, e.g. BRANZ appraisals and CodeMark (via MBIE).
- **Industry Association guidance**: currently there is limited acoustic specific information available through industry associations. Some such as documents provided through CCANZ, Timber Design Society, tend to focus on certain structure types, but do provide some generic information in these areas. The Association of Wall and Ceiling Industries is currently working on a Codes of Practice for Partitions to complement its one on Suspended Ceilings, with some acoustic considerations (though with a more commercial building focus).

At present, information is scattered and finding the information relies on internet searching or knowing documents exist, as there is no central point identifying the most relevant resources to use.

In particular, the documentation supporting compliance is very limited in scope, and offers little general guidance. Although professional advice is available for details, having a starting place for basic concepts is important for other designers, and wider industry.

As noted by some survey participants (including those in construction) - they would like to understand compliance requirements better (including the criteria metrics) but the building code and compliance documents often refer to details in standards which cost too much to buy just to get a better general understanding of the requirements. NZ standards are publicly available to view in person at certain libraries, but most standards are only available to buy online at large cost, which can be a barrier to full understanding and implementation – hence the importance of providing guidance information.

Although not residential acoustic specific, the DQLS Acoustics Guidelines for Ministry of Education schools [29] includes acoustic and sound insulation fundamentals, acoustic consideration in learning spaces, standard details for wall and floor/ceiling constructions at different performance levels as well as information on windows, doors. This provides a good example of generic acoustic information that can aid designers.

When looking at the documentation supporting regulations available in other countries, it is clear there is much more general and specific guidance available publicly to help raise industry awareness and understanding of the considerations that should be made. These tend to give introductory information, context and reasoning for inclusion, clarification that the minimum level included may not provide good satisfaction levels for some residents (and sometimes information on aiming above the minimum), general information on acoustic considerations and how the code fits in with these. See Appendix E2 for examples of guidelines supporting overseas regulations.

5.2.8.3 EXISTING INFORMATION

There is a lot of information available internationally on residential acoustics/ noise control and construction solutions which can be learnt from, although this is still very much an evolving field. At present the information is largely scattered. Relevant past research is usually utilised in creating guidance / best practice documents, collections of generic solutions, and used for the development of current proprietary system, with further research underway in many areas. Past academic research can also be easily sourced through searches on www.researchgate.net.

Appendix E details some useful resources identified through our research, mostly as reported following Stage 1 but with some later additions. This appendix helps cover in some detail the BRANZ research goal of identifying existing sources of information. The Appendix is separated into

- Acoustic related standards
- Public resources related to residential acoustics: in various different forms such as documents supporting regulations, design guides, product manuals, online tools and software, both from NZ and overseas.
- Ongoing Research: Highlights areas where research internationally is currently focussed, as well as research facility available. Key areas being addressed relate to subjective/objective assessment, prediction methods, and building systems/materials
- Acoustic related organisations – both Acoustic focussed and NZ building related, that may or may not offer acoustic advice publicly.

The main gap is that there is little NZ specific information publicly available. Although people can use information from overseas sources (e.g. construction details from an overseas guide) they are likely to use different standards which may /may not meet regulations, and may / may not use materials available in NZ. Confirming compliance of overseas solutions with NZ regulations was highlighted as an issue.

5.2.8.4 ACOUSTIC RELATED ORGANISATIONS

In New Zealand, the key independent acoustic bodies of interest are

- The **Acoustical Society of New Zealand (ASNZ)**: a society for anyone with an interest in things acoustics related, with a special membership grade for professionals actively working in the field (providing NZ certification of Acoustic professionals). They hold regular meetings and produce an academic style journal "New Zealand Acoustics", with all back issue articles publicly available online at www.acoustics.org.nz, and a LinkedIn page at www.linkedin.com/groups/4344490. The site does not provide generic guidance advice to the building industry.
  The Australian Acoustical Society plays a similar role in Australia, www.acoustics.asn.au
- The **Association of Australasian Acoustical Consultants**, at www.aaac.org.nz , is a recent arrival in the NZ setting, having in late 2016 changed its title from Australian to Australasian. This group has acoustic consultancies as its membership (with NZ companies / branches just signing up in the NZ region), and can play more of an advocacy role, for example through recommendations, guidelines and codes of practice. Existing guidelines on the AAAC site are currently based around the Building Code of Australia and Australian regulations.

"The AAAC is a not-for-profit peak body representing professionals who are involved in delivering acoustic solutions to a wide range of clients and the community." - www.aaac.org.au, 4/6/2017

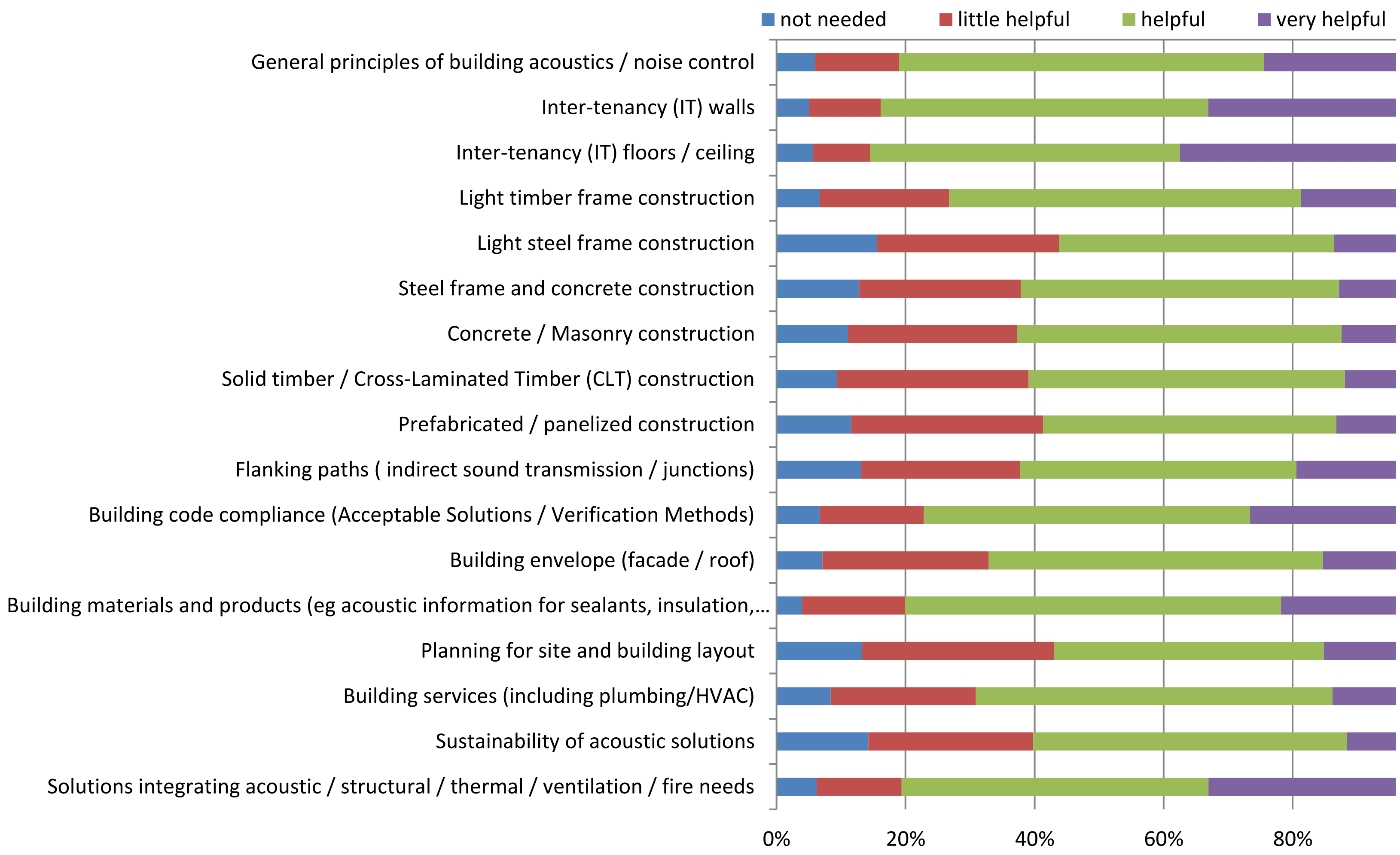
For professional acoustical consultancy, NZ is reasonably well provided for with a number of specialist acoustical consulting companies operating across the country, though primarily in major urban centres, There are also sometimes acoustical engineers or teams within larger multidisciplinary consultancies.

Appendix E4 offers a more complete list of organisations with an acoustics focus, or NZ construction related organisation for whom access to acoustic information might be beneficial.

5.2.8.5 INFORMATION WANTED BY INDUSTRY

Question 11 of the survey aimed to identify areas people felt they needed more information to be available – see Figure 7 below for a graphic of fixed responses, further discussions in Appencix G question 11. People had the option to prioritise three areas as “very helpful” which showed information on IT Floors, integrated solutions and IT walls were the key priorities, with more on compliance, acoustic basics and products close behind. However, the spread of responses shows that more information across the board would be helpful, with only a small proportion indicating there was sufficient information available in each area (more info “not needed”)

Figure 7: ***"Towards Quiet Housing" Survey Question 11: For good acoustic outcomes in MDH projects, how helpful would more acoustic related information be in the following areas?*** **Responses shown proportionally for each topic (approximately 380 responses for each) – respondents were asked to limit choosing the "very helpful" option to 3 areas to help prioritize key areas**



5.2.9 INDUSTRY CONSULTATION SUMMARY

As noted in section 3.4, Stage 2 of this project involved extensive industry consultation on what are perceived to be the key issues, information needs and gaps. The "Towards Quiet Housing" survey was the key consultation tool for this and provided extensive feedback and commentary on industry perspectives. Distribution was to a wide cross section of building industry participants through the BRANZ email list, 696 people started the survey with 414 completed surveys (but also partial responses from those that started). Not everyone answered all questions but there was a large proportion that offered commentary as well as selecting from multi-choice answers (all questions allowed for comments). There was very positive feedback on the survey and efforts to make improvements in this area.

Much of that qualitative feedback is incorporated throughout this report but the full consultation results are provided as two separate documents given their size,

- Appendix G - Stage 2 Industry Consultation – full discussion of consultation and survey methodology plus question by question analysis, interview notes and case studies / practical examples identified.
- Appendix H - Toward Quiet Housing Survey Raw Info – can be requested from BRANZ. The tables of anonymised comments make for very interesting reading, showing the full range of industry perceptions on residential acoustics and noise control, and were provided to BRANZ to allow others to do further analysis and deeper interpretation if desired and to provides grass roots evidence for conclusions drawn in this report. People have also used the opportunity to vent on various other building industry concerns.

To gauge the full extent of the information gathered, here is a summary of the question areas posed in the survey. The questions listed below are abbreviations of the actual questions asked.

- Question 1 – Role in Industry?
- Question 2 – Relevance of acoustics to you?
- Question 3 – Self assessment of acoustic knowledge (in design/construction/compliance)
- Question 4 – How often end users specify acoustic comfort in MDH requirements?
- Question 5 – End user feedback on acoustic performance?
- Question 6 – Relative concern levels for different noise sources?
- Question 7 – Thoughts on the NZ building Code Clause G6?
- Question 8 – Thoughts on an Acoustic Star Rating system?
- Question 9 – Other drivers for acoustic design?
- Question 10 – Acoustic information: sources used?
- Question 11 – Areas where more acoustic information is needed?
- Question 12 – Thoughts on product range in NZ?
    - Question 12a: Practical innovations needed?
- Question 13 – Research and development needs?
- Question 14 – Useful overseas information/solution to share?
- Question 15 – Goto place for acoustic knowledge?
- Question 16 – Best education methods?
- Question 17 – Other thoughts on information and solutions?
- Question 18 - Thoughts on acoustic quality in NZ MDH?
    - 18a: Role of acoustic quality in MDH desirability?
    - 18b: What do we do well in NZ in terms of noise control for MDH?
    - 18c: How often MDH projects aim well above regulatory minimums?
    - 18d: Three key issues that need addressing?

- 18e: Steps to address these issues?
- 18f: Any other thoughts on quality?

- Question 19 – Effects of acoustic considerations on affordability?
- Question 20 – Practical Examples to offer?
- Contact details / Final comments?
- LAST THOUGHTS?

What do we do well?

There were plenty of suggestions of areas for improvement across many different areas in the survey, but we also asked what people thought we currently do well in relation to noise control (Q18b), which is probably worth a mention here as part of the current state of play. We were surprised at the negative response, with almost a third of the responses to this question being negative, (e.g. not a lot, we do poorly, can't think of anything etc.), while even those that offered positive comments sometimes were somewhat qualified (e.g. at least we have some regulations).

There is perhaps some bias in this result as perhaps those with particularly strong opinions in this area undertook the survey, but there was certainly a sense that there is a lot of scope for improvement.

Key positives noted were that: we do have regulations in this area which are reasonably straight forward (some thought work well, others noted room for improvement); there is a reasonable range of inter-tenancy wall solutions especially for terraces (IT floors are the weakness); recent changes for energy efficiency have helped acoustics (e.g. extra insulation and double glazing); generally awareness is growing, with more products becoming available, and professional advice being sought more.

5.2.10 OTHER AREAS HIGHLIGHTED IN CONSULTATION

The focus of this report is on noise control in MDH, with housing in general covered as above. However, several other areas were highlighted as worthy of attention during our investigations. Key amongst these were

- That there is a need for more independent information on noise control and acoustics generally, not just for new MDH, but for standalone and high density housing, retrofitting existing dwellings, other forms of residential and medical care facilities, education facilities, temporary accommodation, offices, workplaces.
- Concerns about high building material costs in NZ generally, and the need to help encourage greater competition in the manufacturer / supplier market. (Though others noted that with NZ being a small isolated market we can't expect similar product ranges to overseas)
- Concerns that margins are so tight on building projects because land prices are so high, part of larger housing affordability issues
- Lack of training for those in construction generally.

5.3 GENERAL ISSUES

Many of the key issues around acoustics for housing in NZ stem from the fact that increasing housing density in NZ has only accelerated in recent times, with skills in this area just developing in NZ, alongside growing awareness of the importance of protection from noise. Helping industry to understand the reasons for providing better noise control, and providing better access to NZ specific technical information, and education is key. Others relate to regulations, compliance, changes in building materials and techniques and even how the building industry operates.

This section focusses on general issues, with the following section detailing specific information needs and gaps. The following general issues and information gaps, in relation to noise control for MDH, have been identified as key priorities:

- **Lack of awareness and baseline understanding** across industry, and the need for increased education and training in this area (see more below)
- Key information gaps relate to
  - **Insufficient independent (rather than proprietary) information** and guidelines supporting basic principles, regulatory requirements and compliance, and good practice. Having independent information available and readily updateable is important, since full regulatory changes can only occur infrequently.
  - **A need for a greater range of detailed generic building solutions** that are code compliant (preferably across multiple design areas, not just acoustics), practical, robust, and cost effective. Ideally these are wanted as Acceptable Solution details whose use also confirms compliance with the building code.
  - **Integrated design,** needing more information on how to integrate acoustic solutions with other aspects of design.
  - A desire for **independent best practice guidelines** – including criteria and features needed for different performance outcomes, not just minimum regulatory requirements (good/better/best)
  - **Clarity around using alternative solutions**, both for compliance and getting these into wider use - including overseas and innovative products
- **More consistency needed in compliance** with regulatory requirements, to ensure actual outcomes meet standards designed to. Different Building Consent Authorities have different methods of assessing compliance with G6, and many different interpretations are possible (see section 5.2.5.1), and different approaches to dealing with external noise reduction.
- The **need to ensure regulations evolve** to meet the health, wellbeing and amenity needs of residents as discussed in Section 5.2.5.1
- **Need to better incorporate feedback systems** during building projects and post occupancy, to better facilitate improvement to solutions and regulations. Survey feedback noted there are few systems in place within the building industry to systematically monitor the effectiveness of design solutions, i.e. a lack of feedback between end-users, designers, contractors. Regular feedback would help to monitor and improve performance, regulations and solutions: With developers usually between designers and end-users in MDH developments that disconnect is even more pronounced. Feedback may occur on a haphazard basis and changes may occur when significant problems are raised by end users through complaints and legal action but incremental improvement through post occupancy data gathering are not par for the course.

- **Product range** could usefully expand to include more fully tested, cost-effective, robust, compliant systems – both generic designs and proprietary systems - and products to support these. This could include research to improve systems currently in use, adoption and import of overseas methods and materials, or using these for development of new systems.
- **Cost issues** centred around additional material costs in NZ, both for general building and acoustic specific products, and the cost of specialised design advice and compliance requirements.

Lack of "awareness":

This was the key theme that came through the Stage 2 consultation, with consequent lack of priority and understanding, and the need for wider education in this area. This is in part due to the relative newness of widespread attached dwellings in NZ. Without basic understanding and buy-in at all stages in the building process, outcomes will not be as positive, hence the need to boost the baseline level of understanding across industry - for example even if there is a good design, it can be let down by poor construction and vice versa. One problem is that good acoustic quality is an 'invisible' feature of a building, and like many sustainability features is less directly marketable than immediately visual features such as fancy taps or kitchens. When acoustic design is done well you don't notice it, but if not there can be significant negative effects. Lack of awareness applied at all levels including

- **End users:** As noted in the survey responses, end users tend to range on a scale from having poor expectations (e.g. put up with noise or just move, or blame the neighbour rather than the building) through to expecting the building code to ensure virtual 'soundproofing'. Until experiencing poor noise control and/or understanding what can and can't be achieved though the building design, end users won't be adequately driving design requirements for the new build housing market until higher proportions of end users have lived in MDH
- **Developers:** As noted previously, MDH is developer driven. For many survey respondents, ensuring developers have good awareness of acoustic considerations was seen as critical. Without sufficient early integration in the design process and an understanding of the cost benefits and importance to end users, it was noted that noise reduction techniques were often amongst the first items on the chopping block when balancing building project needs and costs.
- **Designers (eg architects, acousticians, engineers and other design consultants):** Awareness of the importance of noise control but also of the range of options available to implement good sound reduction in practice, how to integrate acoustic with other design needs and with how to provide sufficient detailing to get the design met. Knowing enough to know when to seek professional acoustic advice was also seen as important
- **Contractors/Installers:** Awareness of basic acoustic principles was seen as important to ensure contractors understand the full implication of changing materials and details (e.g. there may be a reason for a particular density of wallboard or separation distance), and to avoid critical workmanship issues (e.g. importance of sealing airgaps behind skirtings)
- **Suppliers / product developers:** awareness of end user needs and potential markets, and how to get products tested and introduced successfully into the market for wide-spread usage, including to meet compliance needs of alternative solutions under the building code. Awareness of options for independent product appraisals (eg BRANZ, CodeMark). This was noted as especially important for innovative solutions and adoption of overseas products.
- **Building officials:** ensuring sufficient understanding to ensure good assessments for compliance.
- **Urban designers / planners**: Need to understand the effect of their decisions on the noise environment for housing developments.

5.4 SPECIFIC INFORMATION NEEDS AND GAPS

In addition to the general issues noted in the previous section, the following tables summarise the topic areas where information is needed by the NZ building industry to produce "quality, affordable, desirable MDH in relation to noise control", along with information gaps and suggested improvements. Much the same information requirements apply across all housing types (detached, semi-detached, terrace and apartments), not just MDH. Exceptions include that inter-tenancy considerations are not required for standalone houses, inter-tenancy walls are the primary concern for terraces/semi-detached houses (though common floor slabs and lengthwise structural ties need to be considered), and that higher-level apartment blocks tend not be built with light timber framing and have more structural constraints.

For any one sector of the industry only certain parts of this information will be relevant but this covers what needs to be known overall.

Tables include:

- Basic Information – impact of noise on health and amenity (e.g. why it's important!), acoustics and noise control fundamentals for housing including explanation of metrics used, cost benefit information, key information sources
- Inter-tenancy wall/floors – performance criteria, compliance, IT airborne noise, IT impact noise,
- External noise / Ventilation – performance criteria, compliance, exterior envelope design (windows and penetrations), ventilation,
- Building services – plumbing, HVAC, other mechanical (e.g. lifts, garage doors)
- Other building considerations - internal walls/floors, reverberation, building noises (eg creaking, wind whistles), noise within the home, rain noise
- Integrated design
- Sample solutions
- Planning and Layout
- Materials
- Construction
- Renovations

As this is intended as a checklist of sorts, reference to further information for topics are provided in brackets with the number of the relevant section or appendices in this report. For more detail on industry feedback referred to, see Appendix G and H

5.4.1 BASIC CONCEPTS

There should be an independent source dedicated to basic concepts and fundamental ideas which are a priority to get across. Often manufacturers or suppliers provide relevant information (eg www.soundproofingcompany.com/soundproofing101) but people want to have sources of independent information that they feel are unbiased.

Basic Concepts Topic area	Key information needs	Gaps / improvements
Noise: Health, wellbeing and amenity	Why addressing noise is important! • Basic information on the health, wellbeing and amenity effects of noise, and the benefits of good noise control / sound insulation – this is needed to encourage people to take the issue seriously. (See Section 4.2 re noise effects)	• There is an awareness noise is an issue but lack of clarity on specifics, so a collation of information on health and amenity effects could help with marketing the need to address noise.
Basic Concepts	• Basic information on acoustics and noise control relating to housing, including basic understanding of sound transmission and sound insulation techniques and an outline of the basic approach to designing buildings for noise control • Introduction to NZ regulations regarding residential noise • Explanations of the metrics used for acoustics (eg STC, L_{Aeq}, R_w, NRC), so people can better understand acoustic reports and make informed comparisons of product information, including those from overseas where different metrics are used. • The importance of considering acoustics at the preliminary design stage, integrating well with other design areas and construction to achieve good cost effective outcomes.	• Although this information is readily available, even just using a google search, it is scattered, and you need to know what you are looking for to some degree. The information needs to be available in an easy to digest online format, in a trusted NZ location – both in a simple form for beginners, plus more detailed information for reference by the more experienced.

Basic Concepts Topic area	Key information needs	Gaps / improvements
	Raising awareness that whole building system performance must be considered as acoustic performance is dominated by the weakest link (e.g. a high spec wall with poor junction design and lots of flanking transmission, might perform worse than a lower spec wall with good junction details) (see Chapter 4 and Appendix C re background principles)	
COST BENEFIT	Although in an ideal world health, wellbeing and amenity should be the key driver, in practice our consultation shows cost considerations are just as much if not more of a driver for MDH projects. • *Clear presentation of cost benefits and marketability:* To encourage incorporation of good noise control, there needs to be clear information available to support the need and benefits for any added costs, especially for developers and contractors managing the overall budget. Providing information for use in the promotion of good acoustic quality is therefore important, e.g. stats of occupier satisfaction levels for different standards etc. Others in the project (e.g. designers) may push for good acoustic comfort but there must be buy-in at the management level. (See Section 5.2.3 re drivers of acoustical design, and D3.8 on economic considerations).	• During the consultation, it became clear industry wants better information available on satisfaction and dissatisfaction levels amongst residents for different levels of noise control to choose appropriate building criteria (not just based on acoustic consultants recommendations). Ideally this should be specific to NZ construction and expectations. Though there is some international information, the team could find few NZ specific resident surveys, at least publicly available, which specifically compare actual building performance or NZ constructions used with resident satisfaction levels. • International efforts note that local differences mean local assessment is important, with moves to develop a common post-occupancy evaluation tool for international use [12]. This type of post-occupancy information could help with promoting better noise control, as well as highlighting any changes needed to minimum requirements in NZ regulations. Feedback can also help with ongoing improvement to building systems available. (see 6.2)
Best information sources	• Links to relevant organisations and quality online resources for more in-depth information if wanted	• Currently most acoustic information related to housing is very scattered and there is very little NZ focussed material beyond

Basic Concepts Topic area	Key information needs	Gaps / improvements
	- apart from acousticians, most in industry won't have access to specialised building acoustics or noise control resources or tools, and might just want the occasional reference to relevant, up to date information they know is trustworthy. (See Appendix E for information on existing information resources)	summary pages within broader housing or apartment guidelines. There is little awareness of where to look or exactly what to search for. • Providing a central government backed repository specific to helping the NZ building industry build quiet housing, could be most helpful including: general information (both text based and educational videos), technical information, proven solutions and calculation tools, research, case studies, further links and perhaps even discussion groups and feedback systems.
Final Outcomes – End users	• It would be beneficial to home owners/occupiers to understand the objective acoustic performance of the building in a readily understood format • It is also important to reinforce to residents that there is no such thing as 'sound proof', and consideration for neighbours is still important. I.e. clarifying the difference between what the building can achieve for everyday noise, and pointers for what to do for excessive and out of the ordinary noise (e.g. like that provided at www.consumer.org.nz/articles/noise-control) • Tenancy guidelines relating to noise may also be a useful tool to help avoid conflicts. (See also 5.2.7 and 6.1.3 re classification schemes and outcome clarity)	• At present in NZ there is no simple method to classify the acoustic performance of a building (no classification or star rating type system) to help end users understand performance or developers to market better performance beyond 'exceeds NZBC minimum requirements' which must legally happen in all cases, but doesn't indicate by how much. • Even creating standardised acoustic test reports that are part of the compliance process for a property and available from council on request (with a guide to understand them!) would be a start. This could provide a good level of transparency. • It is probably only once understanding levels and information availability increases that some form of formal star rating system can be introduced or an international classification system adopted (various are under consideration).

5.4.2 INTER-TENANCY WALLS/FLOORS

Noise from neighbours within the same building and noise from external sources are the two biggest areas to address. The first is addressed in this section, and external noise is dealt with in the following section.

For more info on NZ Building Code Clause G6 see sections 5.2.5 and D2.1, and more detail on inter-tenancy walls and floors in sections D2.2 and D2.3

IT Wall/Floor Topic area	Key information needs	Gaps / improvements
Performance criteria to use	• When determining what level of acoustic performance to aim for it is important to consider – the legal requirements, the types of noise sources likely in neighbouring tenancies and spaces, expectations of acoustic comfort levels by likely occupiers. • Understand the scope of the current G6 legislation regarding inter-tenancy airborne and impact noise. • Understand what the sound insulation descriptors mean in practice – e.g. what STC 55 and IIC mean in practice • Clarify the performance criteria to work towards - G6 minimum levels or higher? Determine which parts of the building to address – e.g. criteria for shared walls/floors between abutting occupancies as in G6, or ideally extend to cover other areas such as ➢ walls/floors shared with common spaces and service areas (e.g carparks ➢ criteria for entry doors from common spaces / corridors (e.g. solid acoustic rated door with good air seals)	• Continue working to update G6, including clarifying the best minimum levels to use and the scope to cover. See 5.2.5.1 for further discussion • Aim to better inform the debate around whether the current G6 levels are sufficient as a minimum or should be raised, through better NZ based feedback (post occupancy information incorporating subjective occupier feedback and objective building performance). (See 6.2.2) • Methods for demonstrating different sound insulation performance to designers, developers and end users could be beneficial to better inform building decisions. (e.g. through virtual reality simulations andr auralisation – sit in a virtual apartment and hear what the neighbours stereo, voices, footsteps, sound like for different wall /floor constructions and STC values, or how traffic noise sounds inside for different windows or façade constructions).

IT Wall/Floor Topic area	Key information needs	Gaps / improvements
Compliance method	• Information on options for compliance including what information needs to be provided when using alternative solutions rather that NZBC "Acceptable Solutions". • Confirm as part of the planning / consenting stage which combination of – G6 "Acceptable Solutions" – Professional approval of the design, PS1 – Acoustic testing post construction/pre occupancy – G6 "Verification Method" – Final producer statement PS4 will be used for compliance with G6. For example, in Auckland, there should be design approval, visual council inspections during construction, a sample of units must be tested and PS4 provided for multi-storey residential units with IT floors. • Advice on options for checking a design will meet requirements – e.g. professional advice, modelling / prediction software, product specifications • Acoustic Testing – general introduction to the testing process both for airborne and impact noise (survey respondents noted wanting a clearer understanding of what is involved)	• **As noted in section 5.2.5.1 – the current G6 wording is open to a number of different interpretations in some areas, and some definitive guidance from MBIE would be beneficial for clarity, even if a new code is not implemented.** • Different building consent authorities (BCAs) assess G6 compliance in different ways. Providing a national guidance document for BCAs could help provide some consistency (eg perhaps a modified version of "Practice Note ac2204 - G6 airborne and impact sound" used by Auckland Council [22]). • There have been some issues overseas with compliance using just a design signoff, with compulsory post-construction (pre-occupancy) testing or stricter monitoring and checklists during construction introduced in recent regulatory updates internationally. "Prescribed Details" or Acceptable Solutions are still favoured as part of the process in most regulations, as they reduce the need for specialised custom design, and surety that the design should work. However, given the sensitivity of acoustic design to component changes and workmanship, various forms of mandatory construction monitoring and testing requirements have incentivised better outcomes, and should seriously be considered for widespread adoption in NZ. (Many in our consultation were positive about the use of compulsory testing for apartments in Auckland, but those who weren't were concerned with what happens if the acoustic tests fail, how to reduce risk, and the cost of testing)
Inter-Tenancy (IT)	• General information on the effect of different constructions on sound insulation outcomes. Sample details and case	[The following points apply for both airborne and impact noise]

IT Wall/Floor Topic area	Key information needs	Gaps / improvements
Airborne noise	studies demonstrating the effect of different solutions on outcomes was also seen to be useful. • Access to good quality acoustic performance information for building elements (walls, floor/ceiling assemblies) for airborne noise – e.g. manufacturer info, test results, BRANZ appraisals • General understanding of approaches for reducing flanking paths through junctions and why this is important. • Understand the need for junction details that reduce flanking transmission including at the following junctions (here IT Floor refers to the combined floor/ceiling assembly) – IT wall to IT floor (including T and + configurations) – IT wall to ground floor / sub floor – IT wall to IT wall – IT wall to external wall / façade – IT floor to external wall / façade – IT wall to roof (skillion or with cavity) – IT wall to internal walls and floors – IT floor to internal wall • Information on ensuring penetrations such as pipework and electrical sockets don't significantly affect the performance (sealing air gaps, isolation, extra insulation). For residents,	• At present, there is very little publicly available information on generic solutions that work in the NZ market and more are wanted (eg more Acceptable Solutions in G6 or solution guidelines). The resulting gap is filled by several major proprietary system providers (eg inter-tenancy wall and floor systems). However, to allow greater choice people were keen to have more independent information across multiple structure and material types rather than just those used by major manufacturers. ➢ Key gap to fill is full details for a greater range of generic, NZBC compliant (G6 integrated with other relevant code requirements – e.g. fire, structural, thermal), cost effective solutions and systems, and any research that supports the development of these. (see also section 6.2.3) • For acoustic professionals, need better information for assessing flanking noise and junction design. There is still work to do on prediction of airborne and impact noise transmission, but much international efforts on this which should be monitored – BS EN 12354 is most relevant for most construction, except for light timber structures and some newer construction methods where further research is still needed and ongoing internationally. • Low frequency noise (eg bass frequencies from the neighbour's TV or stereo, or thump from footsteps) is still often an issue especially for lower mass systems. Follow the outcomes of current overseas research into methods for reducing low frequency noise transmission especially for light timber frames.

IT Wall/Floor Topic area	Key information needs	Gaps / improvements
	awareness of the possible impacts of penetrations in IT walls (eg picture screws bridging resilient rails, leaving open holes)	
Inter-Tenancy Impact noise	• Access to acoustic performance information of building elements to direct impact transmission (floor/ceiling assemblies), and detailed junction information to reduce flanking transmission as covered above. • Carpet on heavy underlay has been widely used in the past as part of the solution to meet impact noise requirements. However recent trends towards hard flooring means there is a need to provide information and solutions that can meet impact criteria for hard floor surfaces. • Highlight the need to avoid mounting noise sources to Inter-tenancy walls (eg tv/phone to wall), use of soft closing doors/drawers on IT walls to reduce slamming, and use of rubber isolators for appliances on IT floors (to reduce impact noise) • The need to consider if there are special areas where attention needs to be paid – e.g. balconies which are counted as part of occupancies, a roof terrace space. • An understanding that, although G6 determinations mean that although only vertical impact testing is required, horizontal impact noise transmission through common flooring can mean impact sounds may be heard in adjacent and diagonally positioned dwellings – again the importance of junction design to reduce flanking paths.	• This is sometimes seen as an add-on rather than integral component to consider as part of the whole floor design. Although a certain amount can be done through flooring surfaces over the sub-floor structure as below, there needs to be broader awareness of the need for whole floor design to meet airborne and impact needs. • Better information needed on isolating hard flooring surfaces from the floor/ceiling assembly to reduce impact noise transmission in the NZ context (both direct and flanking). Floating floors are widely use overseas but there seems to be some resistance to these in NZ. Need to understand why and provide clear information on options and reasons for usage. • Better information on reducing impact noise for light weight timber inter-tenancy floors, especially in combination with impact reducing systems as above, including true cost comparison information for light weight versus heavier systems (including not just materials, but labour and install times, possible interruptions, availability, performance etc.) • Generic details available to assist with areas not covered by G6 – e.g. door closers, TV mounting

IT Wall/Floor Topic area	Key information needs	Gaps / improvements
	• Building services (e.g. Mechanical systems and pipework) can also produce impact noise – see building services below	

5.4.3 EXTERNAL NOISE / VENTILATION

Again, integration with other areas is important (see section 5.4.6) and see also rain noise (section 5.4.5). More in- depth discussion of external noise is given in sections 5.2.5 and D2.4

External Noise Topic area	General information needs	Gaps / improvements
Performance criteria to use	• When determining what level of acoustic performance to aim for it is important to consider – the legal requirements, likely site specific external noise sources, expectations of acoustic comfort levels by likely occupiers. • Understanding that external noise is dealt with through the Resource Management Act and District Plan requirements for controlling external noise levels and external envelope sound insulation & ventilation. • Beginners guide to terminology commonly in use for external and internal sound levels (e.g. L_{Aeq}) and measures of façade sound insulation (e.g. $D_{tr,2m,nT,w}$+ C_{tr}) • Determine the appropriate performance criteria to work towards in the relevant district plan, and decide if the listed minimum sound insulation / ventilation requirements are sufficient to meet end user needs and expectations. ○ There may be localised sources not directly covered in a plan that still need to be addressed ○ Feedback in our survey indicated that general neighbourhood noise even in quiet planning zones can be an issue as density increases and should be actively considered as part of façade	• Having different formats and requirements in different district plans can make for issues with identifying requirements, implementation of compliance, transfer of knowledge etc. • Support adopting some sort of standardized approach to planning requirements for sound insulation, though with some flexibility to local needs. This would involve choosing an approach to adopt ie 1) specify a value for the façade sound insulation (ie what level drop needed from outside to inside with windows closed) or 2) designing the façade performance to meet a certain quiet level inside based on the greatest level expected outside Both approaches are currently in use in different NZ and international regulations. The 2016 G6 proposed update was looking to standardize outcomes via the second approach • Need clarity around the impact of adding external noise sound insulation and ventilation requirements within the Building Code – there seems to be some disagreement over whether setting a minimum in the building code would overwrite all district plan requirements (or if these remain in effect where higher standards are required to meet local conditions) (See 5.2.5.2

External Noise Topic area	General information needs	Gaps / improvements
	design. For example, perhaps the building is in a quiet residential zone with no regulated requirements for the façade, but one wall is next to the building's main access path or driveway, right next to a busy road corner, or right next to the buildings communal courtyard. Providing some level of protection should at least be considered.	
Compliance	• Clarity around what acoustic information needs to be provided to councils as part of meeting the planning conditions and/or resource consents. Not being part of the building code, external sound insulation is not covered by the building consent.	• As for G6 compliance and the box above re criteria, standardising council approaches, for confirming that external sound insulation / ventilation meet planning conditions, could help provide better levels of compliance.
External noise reduction	• Clear information on how noise travels through the façade and roof, and areas where most care is needed, especially any special characteristics of the façade which might need consideration. • Information on the influence of windows and airgaps which are generally the predominant factors in the effective sound insulation of the whole façade (noting too that the overall sound insulation of a façade is usually much lower than that of an IT wall). General information on the acoustic reduction from different common window glazing and framing options to help with product comparison. • How ventilation paths, such as trickle vents, affect the acoustic performance	• Use of Curtain Walls (non structural outer covering of the building for weather proofing, e.g. a whole glazed facade typical of commercial buildings) was noted as beginning to make an appearance for residential housing. There is little information on this usage in the residential context, with mullion design needing careful attention at IT walls/floors to avoid flanking noise transmission. • The introduction of use of ventilation cavities and rigid insulation in external walls causes acoustic complications which need further investigation: ○ Firstly, the air cavities and rigid insulation create resonances that can significantly downgrade the low frequency performance of a wall. This can require significant additional wall linings etc. to provide protection against sources such as traffic with significant low frequency energy.

External Noise Topic area	General information needs	Gaps / improvements
	• An understanding that some balance is required – ○ if the external noise is reduced too much, so that internal background levels become very low, internal noise becomes more apparent, IT noise transmission becomes more apparent and there can be added issues with privacy (see 'masking' discussion in NZS 2017 [[11]). • The influence of the facade as a flanking path between units requires consideration	○ Secondly the cavities act as a potential flanking path for sound to travel between units vertically and horizontally. Detailing appropriate junctions requires careful collaboration of both acoustic and water tightness. •
Ventilation and Thermal comfort	When housing is in noisier zones (eg inner city, by traffic corridors), ambient noise levels inside a dwelling with windows open can be well above recommended levels [NZS2107], since with windows open sound levels are likely to be approximately 15dBA lower than outside, whatever the rest of the façade design. Many district plans therefore require façade designs in certain zones, to either meet a particular internal sound level or a set level of sound insulation, with windows closed. This has a knock-on effect to other areas – primarily ventilation requirements, hence ventilation and sound insulation requirements are listed together. Even with windows closed, air flow is still required for air quality and humidity control, as well as for natural cooling if an active cooling system is not available. (see also D2.4 and D3.3) • Clear information on the need for "windows closed" sound insulation / ventilation requirements	• Our consultation supported the need for better understanding of external noise / ventilation requirements. This was especially important as this is an area seen to add considerable cost through HVAC requirements. • Improve understanding of why this is an important requirement as this is necessary for buy-in from all involved – **that it is a cost penalty incurred through developing housing in the non-ideal acoustic surroundings of many MDH developments.** • Limiting internal air temperatures is not part of the current Building Code. Even when 'ventilation' systems are required for acoustic purposes these are often designed to meet minimum code requirements and do not consider the high temperatures experienced in units during summer. To meaningfully address issues with MDH in high noise areas requires strong guidance and/or changes in legislation relating to indoor air temperature. • More information is needed on the options for passive ventilation with good acoustic performance, and quieter HVAC systems. There seems to be a somewhat limited supply in the NZ market of acoustically treated

External Noise Topic area	General information needs	Gaps / improvements
	• Good information needs to be available on options for passive and active ventilation. This includes the general approaches that can be taken and information on the metrics used for assessing these systems – both for noise and airflow. •	passive ventilation systems such as 'acoustic trickle vents' and technical information is difficult to find and apply.

5.4.4 BUILDING SERVICES

See Appendix D2.5 for more information on regulating building services noise and D3.3 for in depth discussion in relation to ventilation / HVAC

"Building Services" Topic area	• Key information needs	• Gaps / improvements
Building services (plumbing and mechanical)	Although there are no specific regulations on building services noise in NZ, this is still a reasonably large area of concern that is commonly regulated for in other countries. It is therefore important to have information available on: • Techniques to reduce noise from services through things like isolation from building structure, lagging, and choice of components. • Clear information on techniques used to test building services noise and commonly accepted noise levels for different types of services. (Again information should be readily available on metrics used)	Our survey indicated there was uncertainty on how to address this area, or what tests could be done to check performance, so guidance was wanted.

5.4.5 OTHER ACOUSTIC CONSIDERATIONS FOR THE BUILDING

Although the following areas are less often regulated for than the above (Inter-tenancy, external, or building services noise), awareness of and treatment of the following may be important in some circumstances, therefore having information available for reference is important.

"Other Acoustic needs" Topic area	Key information needs	Gaps / improvements
Internal walls/floors:	Though not required by G6, it is common overseas to have information available on cost effectively improving the sound insulation of internal building elements (e.g. between bedroom and bathroom/kitchen/noisy lounge, garage and living areas), plus noting the effect of doors on performance. *Many codes overseas (especially in Europe) specify sound insulation requirements for some internal walls / floors, or supporting guidelines at least offering advice in this area. Our consultations noted that this was an issue in NZ standalone homes too with our lightweight construction. (see also D2.2.3)	Currently there is only proprietary information on systems or products usable for internal walls, no general guidance.
Reverberation	Though not regulated for in NZ, consultation noted that excessive reverberation can be a concern. Longer reverb times indicate less sound absorption and higher average sound levels in a space, which can be annoying in itself, as well as increasing the amount of sound energy that can be transmitted to other spaces. It is therefore beneficial to have information available on • noise control in common spaces (e.g. reducing reverb time in stairwells, corridors and foyers with mostly hard surfaces) – suggested criteria to work to and mitigation options • Addressing long reverb times in rooms with primarily hard surfaces (especially with the trend to hard floors and blinds instead of thick curtains)	Feedback noted that this is becoming more of an issue, and having access to options for improvement is important for informed decision making.

"Other Acoustic needs" Topic area	Key information needs	Gaps / improvements
	The New Zealand standard AS/NZS 2107:2016 "Recommended design sound levels and reverberation times for building interiors" is relevant in this regard [11]	
Room acoustics and noise within the home	General information for consumers on improving room acoustics (use of soft furnishing), and mitigating effects from room layout and usage (eg moving tv off wall adjacent to bedroom). .	
Building noise	Mitigation techniques for things like • floors squeaking under footsteps, • fixings squeaking when materials expand and contract (eg from heating and cooling of metal roofing) • Wind noise through louvres or railings	
Rain Noise	Rain noise is a form of impact noise but generated by raindrops on the external building envelope (usually roof but also façade depending on wind direction). Especially for those that have grown up with a traditionally kiwi galvanised iron roof, and going to sleep to the sound of rain, rain noise is often not perceived negatively. However, although heavy rain is usually of short duration, rain noise can be an issue for heavy rain above a noise sensitive space such as a bedroom, living room or home office, where sleep or communications may be disturbed. General information on techniques for reducing roof rain noise should be available where this might be an issue. (see D2.7)	Roofing manufacturers often provide some information but there is little generic guidance on what to look for product comparison.

5.4.6 INTEGRATION WITH OTHER DESIGN FACTORS

See also section 5.2.6 for an overview of other design factors influencing acoustics and Appendix D3 for detailed discussion of the key conflicts in each area

"Integration" Topic area	Key information needs	Gaps / improvements
Integrated design	It is important that design disciplines have a general awareness of areas where acoustic considerations can have an impact or be impacted by decisions elsewhere. Ideally there should be awareness of the overlap in the following areas: • **Structural**: integrating structural and acoustic requirements is critical – including minimizing flanking effects through connectivity requirements for structural integrity and seismic needs. (see D3.1) • **Fire protection**: often complementary with acoustics but there can be some issues around intumescent seals and solid fixings. (See D3.2) • **Internal comfort**: Acoustic comfort needs to be balanced with good air quality, humidity control, thermal comfort and natural lighting needs, so should be accounted for when considering: active and passive ventilation, HVAC systems generally, and window areas. (see D3.3), • **External Envelope and energy efficiency:** façade and roofing thermal insulation and water tightness measures and their potential effect on sound reduction and flanking paths. For example: information on windows (thermal and acoustic glazing needs differ slightly), sealants and insulation types (some thermal insulators don't perform well acoustically such as polystyrene); flanking via cladding cavity. (See D3.3, D3.4, D3.5, D3.6) • **Building Services** noise not covered above (e.g. plumbing, electrical, lifts, automatic doors (See D2.5)	It was noted in feedback that currently design professionals (eg architect, acousticians structural / mechanical services / façade / fire engineer), often work in isolation with insufficient awareness of the implications of their work on overlapping areas. This is probably a more widespread issue. Some guidance on key conflict area should be available for reference by different disciplines. Need to raise awareness of the need to get acoustic considerations into the planning from preliminary design stage, so that all design aspects can be integrated most efficiently by the design team as a whole. **Any specific solutions developed by BRANZ need to be approved by all relevant disciplines.** Specific gaps highlighted in feedback relate to needing • Better understanding of the effect of seismic resilience techniques on acoustics (flanking transmission). This has been especially flagged since the Canterbury earthquakes which have lead to greater interest in increasing seismic resilience levels – i.e. increasing the chance a building not only stays standing but continues to be usable following an earthquake. • Meeting ventilation and acoustic needs together when windows need to be closed.

"Integration" Topic area	Key information needs	Gaps / improvements
	• **Architectural** (not covered above): e.g. aesthetics, lighting needs, and influence of trends (e.g. more use of hard surfaces) on acoustic outcomes. (See D3.7)	
Professional advice	• Understand the benefit of professional advice to ensure all aspects considered early in the design process and appropriate details selected since getting the integrated design right early on should end up with a more cost effective overall solution, rather than later requiring mitigation. • If a specialised acoustic consultant is not possible on a team, at least ensure that other design team members involved (eg architects, designers and engineers) have good understanding of acoustic considerations and how to deal with them (see integrated design above) (See D2.9)	• Feedback noted acoustic consultancy was often not used for smaller or cheaper terrace/apartment projects or just not incorporated in project funds even in larger projects, with architects, drafts people and engineers expected to cover this area, but often feeling they lack the necessary skills and supporting information. • Others noted the better outcomes when acoustic consultants were involved, including the knowledge fed through to others in the team Perhaps provide case studies of situations where acoustic advice was and wasn't sought and the resulting outcomes. • Increasing the availability of robust construction details that meet acoustic needs for standard scenarios would allow better outcomes for a broader set of projects where advice currently isn't sought.
BIM	Although only occasionally noted in consultation, increasing use of Building Information Modelling systems should be considered. Note MBIE is also supporting this development (https://www.building.govt.nz/projects-and-consents/planning-a-successful-build/scope-and-design/bim-in-nz/). Building Information Modelling (BIM), the digital representation of the complete physical and functional characteristics of a built asset, could in theory include acoustic information as part of the whole building functionality. (see	Acoustic modelling and information in BIM systems is currently not very advanced, and is an area just beginning to be researched. e.g. http://www.huzhenzhong.net/CIBW78Papers/html/files/1-2pdf/66.pdf). As other areas increasingly use BIM to aid the design process, if acoustics features are not included this may reduce the consideration it gets in the design process.

5.4.7 BUILDING SOLUTIONS

"Building Solutions" Topic area	Key information needs	Gaps / improvements
Sample solutions	• There needs to be quality information available on a range of structure types for informed decision making at the design stage – e.g. both light weight and heavy construction in a range of materials. ○ Handbooks or guidelines with full construction details meeting acoustic requirements, that can be incorporated into project plans, was seen to be very helpful. The aim is not to replace professional advice, but speed the process and reduce the chance of errors during the production of design details – checking the overall design is still recommended. • Survey results noted that with the lack of generic independent information available in NZ, proprietary systems and construction methods of certain manufacturers were sometimes used due to lack of apparent alternatives. Often these proprietary systems work well, but knowing options and having a choice was seen to be important. • Ideally people want access to a good selection of compliant building system details across multiple structure types that are cost effective, buildable and robust, and integrate multiple compliance needs (structural, fire, acoustic, energy efficiency) that can be mixed and matched to needs. This matches with the trend overseas towards modular building for cost efficiency.	• At present, there is a very limited range of MBIE approved "Acceptable Solutions" to meet G6. Some generic solutions are available (including those used overseas) but not widely available with NZ context. Confirming NZ compliance and providing information publicly on solutions that meet and exceed NZ regulations for whole systems was strongly desired. Having more generic system solutions could perhaps help with the issue raised in consultation that available proprietary systems don't always work well together and the need for manufacturers to work together better. • Research to develop compliant sample solutions (both generic and proprietary), ideally each solution should have data collected for and available on a large range of projects incorporating ○ Details used (floor/ceiling / wall and junctions), ○ Full acoustic test results for elements, and prediction of flanking effects ○ Feedback on the robustness of each configuration to construction errors, ease of installation, hidden costs during construction (extra labour, time delays etc) ○ Measured acoustic performance outcomes for completed projects for each configuration ○ Post occupancy outcomes

"Building Solutions" Topic area	Key information needs	Gaps / improvements
	In the absence of such complete information, at least a good range of Acceptable Solutions to work with were wanted. (See Industry feedback – Appendix G and Section 5.2.8 on information sources)	In order to create generic solutions - material properties that influence outcomes need to be fully understood and values listed (e.g. mineral wool or wall board density, stiffness characteristics required of resilient clips etc.) • Databases collecting all this information would allow the closing of the feedback loop for effective ongoing improvement of solutions used and be useful to market successful outcomes. • Partnerships between BRANZ and manufacturers or groups of manufacturers working together to develop cost effective generic solutions would be beneficial. See Section 6.3.1 discussion on the UK Robust Details framework which aimed to address this set of needs, and section 6.2.3 on Building System research.
Innovations and new solutions	• Clear information on the process needed to assess the sound transmission properties of a building system or product (eg options and requirements for acoustic testing in NZ) • Steps to take to certify compliance of a new building system or product with NZ regulations (e.g. the BRANZ appraisal system, successful use in past compliant projects) • Clear understanding of the Building Consent Authority requirements when using "Alternative Solutions" for building code compliance as it relates to G6 • Good quality information and documentation provided by manufacturers /suppliers that	• Survey feedback indicated it was tough knowing where to start when wanting to use new solutions – for example bringing a good product from overseas to use or introducing a new material. This was felt to limit innovations. • Industry members also noted that some products don't provide sufficient information for them to feel confident in their usage (e.g. a glossy brochure but insufficient technical information, compliance information or acoustic test results). • Some newer structural technologies, that people are wanting to consider, do not yet have a full suite of acoustic test result, compliance information, supporting guidance documents, associated supporting product range (e.g. cost effective fasteners, resilient mats, finishes) or case studies of actual installations to

"Building Solutions" Topic area	Key information needs	Gaps / improvements
	○ Helps product users feel confident they fully understand the potential product performance ○ Can be passed on or used by building consent authorities as part of checking G6 compliance of "alternative solutions", or to councils for planning conditions (e.g. window performance as part of sign off for façades.)	allow successful widespread use. Highlighted examples in our consultation: More info is needed on the use of engineered wood (eg CLT) and prefabricated panels for the building structure – flanking can be important with these types of rigid panels, so understanding how to mitigate these effects is essential.

5.4.8 CONSTRUCTION

"Construction" Topic area	Key information needs	Gaps / improvements
Designing with construction in mind	• Raised awareness with designers of the need to consider the buildability of the solutions when choosing which to use. Feedback systems from installers / project managers is important here. • There is a benefit to including buildability information with product and system information (e.g. labour requirements and skills, robustness, install times, possible delays from dry time etc), as these can have significant impact of the overall cost of a solution above material costs alone	• Survey feedback from those in construction noted that some designs and systems can be impractical or cumbersome, but there is no systematic way to feedback this information. One even noted overquoting costs for systems recommended that they knew were too difficult to implement and didn't want to use. Independent review sites were raised as useful in this regard.

"Construction" Topic area	Key information needs	Gaps / improvements
Workmanship	All those involved with the building's construction (including project managers, site managers, builders, contractors, installers etc) need to • Understand the sensitivity of acoustic design details to minor errors in construction • Ensure those constructing solutions have sufficiently detailed plans and installation instructions to work from, especially for junction details. • An understanding of basic acoustic and sound insulation principles, to highlight the effect workmanship errors can have on acoustic outcomes, including practical issues like: \\ ○ not bridging isolating layers (e.g. no debris between double studs, screwing through resilient rails to the studwork); ○ sealing airgaps; ○ potential effect of replacing materials with alternatives, or using different dimensions	• Awareness at the construction phase was highlighted a major issue during consultation. Even with a good design, poor installation can produce poor results. So without systems to validate construction, improvements to design can be irrelevant. • Because many in the construction industry (especially builders specialising in houses) have not been involved with medium or higher density housing, training needs to occur across all experience levels. Even experienced builders may not have the relevant knowledge to pass on to apprentices in relation to inter-tenancy constructions. • Incorporating Acoustics 101 and common workmanship issues should be part of building construction training. Consultations would indicate this is not always the case. • COST Action TU901 includes a full chapter outlining common errors and good practice for design and workmanship – Volume 1, Chapter 10 [12]
Construction Checklists	• Providing a checklist to help with construction monitoring, especially for those unfamiliar with installation of a particular system is useful. Overseas such checklists are often used as part of the compliance process and must be signed off. (see also D2.8)	Some proprietary systems provide this type information as part of installation instruction but others do not and should consider their use Any detailed solutions / guidelines developed should include checklists of key things to watch out for and confirm during construction.

5.4.9 PLANNING AND LAYOUT

"Planning and Layout" Topic area	Key information needs	Gaps / improvements
Building Layout	Guidelines on how to incorporate acoustic considerations in the building layout – e.g. stacking rooms with like usage, room arrangement, services placement etc. (See also D2.6 and D2.2.4)	Would be helpful to collate scattered information into a clear reference guide for use by architects and designers
Planning considerations	Outline of planning considerations related to noise, as an overview for planners. What are the likely planning requirements from district plans and what should be considered by urban designers. (See D2.6)	Would be helpful to collate scattered information for quick reference by planners and urban designers
Noise emissions	That considerations must also be given to the effect on neighbours of noise generated by new denser housing. For example, more traffic and human generated noise from carparking, access routes, outdoor spaces.	

5.4.10 RENOVATIONS AND CHANGE OF USE

Although the focus of this report was on new building work, renovations were also raised during our consultations. Overseas, poor noise control in many older buildings has meant there is quite a bit of information available on retrofit techniques. Although they rarely achieve as good results as when incorporated during original construction, and in some cases can be costly, providing retrofit information would still help the overall housing quality in NZ.

"Renovations" Topic area	Key information needs	Gaps / improvements
Renovations	Renovations in NZ are required to meet certain aspects of the NZ building code (Building Act 2004 Section "112 - Alterations to existing buildings" and Section "115 Code compliance requirements: change of use"), with work done needing to be as close as reasonably possible to current building code requirements. Therefore. there needs to be information available on techniques for mitigating noise where major structural changes may not be possible – ie offices changing to apartments, or large house changing to multiple dwellings.	Currently we could find little detailed information in NZ on retrofitting noise control solutions – though this is a big field overseas. Creating checklists and information on available solutions in NZ would be useful. The extent to which renovations and change of use require compliance with Building Code regulations requires clarity and consistency – at present there is little guidance in this area and different approaches

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6 PROPOSED FUTURE ACTIONS

This chapter contains the core research team's recommendations for future actions which should provide the best outcomes for improving "quality, affordability and desirability of MDH in relation to noise control" including:

- Making information readily available and useable to the building industry, including increasing the building industry knowledge.
- Developing or identifying superior technical acoustic solutions for the industry, including ways to predict and feedback objective and subjective performance.

The chapter is divided as follows

Section 6.1: **Dissemination of information recommendations** – 1) An online "Quiet Housing" hub, hosted and maintained by an independent government backed organisation such as BRANZ or MBIE. 2) A promotion campaign to raise awareness of noise control through building design and the availability of the hub 3) Transparency of outcomes

Section 6.2: **Future R&D**- Based on industry surveys and existing knowledge, we divided the research needs into the following areas: Post-Occupancy Surveys, Building System Design Solutions, and Prediction Methods.

Section 6.3: **Useful overseas solutions** – Three areas are discussed. 1) The Robust Details framework used in the UK, elements of which could be used in NZ, 2) Dataholz.com and 3) Impact flooring solutions used internationally

Section 6.4: **Building Code G6** – some last thoughts on updating G6

6.1 DISSEMINATION METHODS

6.1.1 "QUIET HOUSING" HUB

The main recommendation of this project centres around establishing an online information hub, called perhaps the "Quiet Housing" hub. This would provide independent information as quickly as possible to those in industry, in a format that is easily expandable.

Our industry survey indicated that providing information online, was by far the preferred format as this provides quick access to up to date information from everywhere. Centralising all relevant information in one online hub, hosted by a trusted independent organisation was agreed to be a good approach in survey feedback and from our assessment of the information that needs to be available to best support industry – Section 5.4.

One of the issues that we observed about the continued failures to update G6 (both the building code clause and the supporting G6 compliance document) is that there is one single document where every individual aspect must be agreed upon by most parties as being required in every single case. For the large number of changes being attempted for G6, this can present challenges.

An information hub (with suitable disclaimers) has the advantage that readers have a choice to adopt the information or not, but by readily providing a full range of information, people can make better informed decisions and the site can increase general awareness and knowledge. Such a hub would in no way replace the need for ongoing improvements to regulations, but work to support current and proposed regulations, and give people access to the information needed when regulations do change (rather than scrambling to try to catch up after they are introduced). It would also not be intended to replace professional advice but rather help people understand when and why such help is useful.

The “quiet housing” hub could potentially be a branch of a broader “acoustics” hub, as there is potential to provide independent acoustic information for other building types such as commercial, industrial, schools, short stay accommodation, healthcare facilities etc. Something along the lines of the www.SeismicResilience.org.nz site might be a good starting point.

6.1.1.1 MODULAR INFORMATION

The idea is to provide information in a modular format so people can access the information most relevant to them. ‘Modules’ would cover certain themes and information within modules could be developed separately by those with expertise in each area. By their very nature websites are modular and interconnected and provide the ideal set up for such a modular information hub. New guidelines, articles, “sample solutions”, research findings, tools, resources and links to external resources can be quickly added as they become available, and amendments and corrections quickly incorporated. Our survey indicated people also like to be able to easily print online information, so arranging webpages to have downloadable pdf equivalents, or be well set up for printing, would be useful.

The information included should also allow for different people’s learning styles with information provided or linked to in a number of different formats (part of ongoing improvement to the site once core information is available). I.e. there should be standard text documents with plenty of graphics, educational videos, case studies and practical examples.

It might be useful to also set up a page indicating the most relevant pages for people in different fields – e.g. for a developer pages a/b/c, for a builder pages a/e/j, for an architect pages a/b/c/d/e/h

The basic structure for the hub could follow the outline of information needs given above in “section 5.4 Specific Information Needs and gaps”. Core information could be added first, and expanded with additional information to fill the gaps identified once available.

6.1.1.2 BRANZ BACKING

Given that BRANZ is the trusted building research authority in NZ it makes sense for this “Quiet housing” hub to be hosted or supported through BRANZ, preferably with some form of backing from MBIE (at least as a link from the G6 compliance page). If feedback systems are also incorporated into the hub (eg feedback on further information or product needs, systems that work or don’t work, even perhaps discussion forums) the hub itself could also become a research tool.

The hub would need to be kept up to date and dynamically improved and expanded to provide the most benefit, so would need to be actively monitored and administered which would require some ongoing funding and professional oversight.

Advice should be sought on whether it is appropriate to have an area where manufacturers could list their relevant products and website links (perhaps with links to relevant BRANZ appraisals). Some survey respondents noted having trouble finding information beyond larger manufacturers and wanting greater access to options. Advertising could help with funding the hub – however as the aim is to provide independent advice these ads should not be part of information pages, and only provided in clearly demarcated advertisers pages if at all.

6.1.1.3 SAMPLE SOLUTION MODULES

As well as the general information modules, the research team think it is important that the hub should provide some Sample Solutions for a range of construction types. Ideally people want more MBIE provided “Acceptable Solutions”, perhaps alongside a more complete system such as the UK’s “Robust Details” (see section 6.3.1), but in the meantime providing some sample solutions with feedback systems on the quiet housing hub could provide a tool for the further development of these formally compliant solutions.

It would need to be very clearly stated (with suitable legal advice on wording to avoid litigation issues) that the Sample Solutions offered are for guidance only, and that professional advice is still recommended to confirm designs meet all building code requirements, with testing carried out to confirm compliance where applicable.

We suggest the framework for "sample solutions" would probably follow a similar structure to that used by the Robust Details Handbook (see section 6.3.1 for more on Robust Details), which also includes a table of solutions that work well together.

A sample solution would include:

- A unique identifying code, e.g. ITW-T-1 (Inter-tenancy wall, timber, solution 1) - Others could be ITF – IT floor, INW / INF- Internal wall / floor, EXR – roof, EXF- façade S- steel, C-concrete, E-engineered wood,)
- Detailed drawings for the construction of the "solution", including dimensions
- Listing of the properties required of all components used
- Things to watch for / do - both practical construction issues and design consideration when using this "solution"
- Detailed drawings and comments on areas requiring attention to reduce flanking for all junctions expected with the solution, for whichever of the following junctions are relevant:
  - IT wall to IT floor (including T and + configurations)
  - IT wall to ground floor / sub floor
  - IT wall to IT wall
  - IT wall to external wall / façade
  - IT floor to external wall / façade
  - IT wall to roof (skillion or with cavity)
  - IT wall to internal walls and floors
  - IT floor to internal wall
- A checklist for construction monitoring

Suggestions for improvements to increase performance could also be added, e.g. extra STC points expected if adding additional wallboards, insulation or modifying cavity depths.

Statement of key considerations related to other design requirements in the NZ Building code – e.g. B1 Structure, B2 Durability, C Fire protection – but also confirmation that whole system performance needs to be checked by the relevant professionals.

Appendix F presents a mock-up of a Sample Solution guide using some of the details from the latest 2016 not publicly released proposed G6 update (shared with permission from MBIE)

6.1.1.4 FEEDBACK SYSTEMS

A broader issue highlighted by our survey was that there are few systematic ways to close the feedback loop between designers and end users and to a lesser degree between different areas of the building industry. Post occupancy information is one area we have suggested warrants further research (see section 6.2.2) but closing loops within the industry itself could also be beneficial. Internet users, especially those who have grown up with the internet, are well used to the idea of social media, comments, forums and wiki pages where participants can engage with one another, share ideas and opinions.

There is an option to incorporate feedback systems into the hub. E.g.

- **Page based comments:** providing a facility to comment on each web page or sample solution on the hub, where people can indicate issues with content, suggested improvements, further information wanted. These comments could either be public (would need to be from registered, confirmed users for transparency), public after moderation, or just sent to the site administrator and collated for later action. Requiring registrations or limiting public access to feedback for sample solutions might be necessary to avoid potential issues with commercial interests overtly supporting or undermining certain types of solutions
- **Allowing site registration,** as well as providing transparency for comments, could also allow those users to be notified of module updates – though these notifications could also be done through things like the BRANZ Guidelines newsletter or Build magazine. Making registration compulsory to view resources on the site is not recommended, as the aim is to provide publicly accessible information with the least impedance.
- **Discussion Forum / Review site:** Discussion forums where people can raise and offer opinions on NZ specific acoustic matters was also an option suggested by some survey participants. There was an interest in having an independent location for reviewing products and solutions, e.g. people's experiences of how well a solution worked or the issues they had with product. This has not been looked further but is noted for completeness

6.1.2 PROMOTION PHASE

Once a central repository with basic resources is established, it would be advisable to undertake a promotion phase

- **Industry Awareness:** promote the "quiet housing" hub through industry associations – e.g. planners, architects, IPENZ, HERA, WPMA – or general publications (eg Build magazine) as an opportunity to raise awareness of the topic, and get the site in use, including to generate feedback for iterative improvement and expansion. It is also important to ensure documents being produced on housing actively promote acoustic considerations. Appendix E3 lists organisations involved in construction in NZ who could potentially be worth approaching.
- **Targeting Developers:** Promotion of good acoustic design and early integration in the design process to developers (who are the key drivers of implementation in MDH) – for example through articles in newsletters to developers through industry association like the Property Council's Residential Development Council. Ensure that standard guidelines for designers, produced by developers, actively incorporate consideration of noise.
- **Target Designers:** Via industry association publications and forums, actively seek feedback from designers / architects and technical consultants (eg acousticians, structural engineers), for building solutions they have found to work to provide good acoustic performance while meeting other code requirements, so these can be tested and shared as generic solutions. Aim to engage the industry to actively participate in sharing lessons learnt, case studies, and widen the pool of generic solutions available to all – with results and outcomes added to the hub.
- **Target those in Construction:** to raise awareness of the sensitivity of acoustic outcomes to material choices and workmanship.

Education and Awareness raising programs:

- **Establish a seminar / training series through BRANZ** on Acoustical design for MDH, with follow up online versions of the seminars available – perhaps have "fundamental ideas" seminars freely available online to help raise baseline industry knowledge and more in-depth seminars on a paid basis
- **Professional Courses:** Check professional education programs (architecture, structural / mechanical engineering, planning) include acoustic fundamentals courses with practical content.
- **Construction Training:** Confirm building apprenticeship and BCITO programs include some basic information on acoustic requirements as related to construction practicalities
- **Roadshows:** Possible touring exhibition or roadshow demonstrating acoustic principles in a hands-on way, for public and broader awareness raising. Or a more technical roadshow of acoustic solutions supported by manufacturers.

These promotional aspects could also be done in conjunction with or support of the Acoustical Society of NZ or AAAC – though the exact nature of such a collaboration has not been fully assessed at this time.

6.1.3 TRANSPARENCY OF ACOUSTIC OUTCOMES

The idea of an acoustic performance rating system, was reasonably warmly received in our survey (i.e. a good/better/best or star type rating system to inform occupiers of the level of acoustic performance), though comments on existing building / sustainability rating systems were not always positive. The preference was for an acoustic specific rating, rather than incorporation in a broader rating scheme.

The research team's opinion is that increasing basic levels of understanding within industry (about the options for producing different outcomes) needs to occur before pushing for the widespread use of a consumer acoustic rating system. There is still the option for those that want to utilize the AAAC ratings or one of the international classification systems being proposed. This area should probably be reconsidered in the future.

Rather than establishing a whole new rating industry, another option is increasing transparency of outcomes through the compliance process. At this point this is just an idea, how this would work in practice with councils would need further investigation.

Where G6 or facade acoustic testing or design assessment has been conducted as part of compliance for a housing development, the consenting authority should hold copies of the relevant documentation/ acoustic test results / PS4 (part of the property file usually available on request from a council/building consent authority). It should be possible to create a reasonably smooth process whereby if someone wants to gauge the objective acoustic performance of an apartment or terrace, they go to the consenting authority and request the relevant acoustic test sample results or documents for the development. The Quiet housing hub could provide information helpful for understanding the results. A standardised format or template for presenting test result could be helpful to aid communication with end-users.

6.2 RESEARCH AND DEVELOPMENT

6.2.1 INTRODUCTION

During stage 1 of this project we conducted a summary review of research that was occurring globally in the area of building acoustics – see Appendix E3 for the full review. In essence, we divided the research into three parts: 1) Modelling, predictive and optimisation methods; 2) New building materials, elements and structures; 3) Subjective analysis of Building Acoustics. The existence of such global research reflects demand for this research in a global context.

We observed the following main points from the research summary:

- There are increasingly useful theoretical and modelling methods which are starting to or can be brought to bear on more complex building acoustics prediction problems (such as framed construction methods). These modelling methods will enable designers to assess solutions before being built, as well as allowing more computer optimisation of designs.
- There is a trend to more sustainable, lightweight and prefabricated construction, which is providing more opportunity for new engineered products and digital manufacturing systems, for example CLT. This has led to more research and more demand for research to deal with these new construction materials and methods. The increasing use of digital and other new fabrication techniques also allows more precise and complex structures to be manufactured, which could offer new possibilities (e.g. metamaterials).
- There is still on-going research into the subjective response to acoustics and noise control, which tends to ultimately manifest itself as better objective acoustic indices and performance metrics.

During stage 2 of this project we surveyed the New Zealand construction industry. The following points summarise the relevant R&D relevant industry needs from this survey:

- Minimal feedback is received by designers and builders regarding the acoustic performance of their constructions. Setting up formal post occupancy surveys was suggested. This would help validate designs, relate occupants' opinions to measured rating systems, and identify most important areas of the building to focus on.
- Mixed opinion about whether G6 minimum requirements are adequate would suggest that some research into whether it needs to be upgraded would be required. This couples with the desire to have a better acoustic performance rating/classification system.
- When asked whether practical innovations were needed there were plenty of suggestions, including cheaper ways to test compliance, ways to add mass to buildings (to reduce acoustic problems), reduce air leakages and engaging in technology transfer from overseas. Safer materials, better junction design, integrated, tested systems, and better intertenancy floor systems were also mentioned.
- When specifically asked for R&D needs there was a strong response that R&D would be helpful. There was a mostly even spread of requested needs from building products, flanking paths, prediction tools and end user requirements. R&D into overall building design, however, came out as the number one area requiring further R&D effort (particularly if you consider overall building design includes flanking paths).
- Follow up comments about R&D needs were divided into three main themes: R&D in NZ needs to be aware of and build on overseas R&D to make best use of resources; Acoustics needs to be

holistically considered in the context the overall performance requirements (structural, hygrothermal, fire); and the information must be passed down to the user through education and information resources to make it worthwhile (giving better bang for your buck than R&D). The need for better flooring systems was mentioned again, as was performing post occupancy evaluations to validate designs. A mention of integrating acoustic prediction tools into BIM was made in the survey.

Based on the surveys and existing knowledge of the research team we have divided the research needs into the following three areas: Post-occupancy surveys, Building System Design Solutions, and Prediction Methods.

6.2.2 POST-OCCUPANCY OBJECTIVE AND SUBJECTIVE SURVEYS

There was a strong response by industry for the need for post-occupancy surveys to establish whether a particular construction design is performing acceptably. Such surveys would include subjective surveys of occupants as well as objective acoustic measurements of building performance. By combining objective with subjective surveys one is not only able to validate the acoustic performance of constructions, including variability, but also able to determine whether objective measures appropriately represent the subjective experience and satisfaction of the occupants, which is the ultimate goal.

We recommend that research needs to be done in New Zealand to develop, conduct and analyse New Zealand centric subjective and objective post-occupancy surveys. Such surveys will give feedback on the acoustic performance of particular construction designs. Comparing and correlating the subjective and objective measurements will also enable us to determine whether acoustic insulation rating methods and standards are sufficient and suitable, whether the minimum required rating values are acceptable, and whether there is need to consider the regulation of other noise sources.

Such results will provide objective and on-going New Zealand evidence to prove the need (or otherwise) for building code regulation improvement, and to determine whether there is merit to developing rating /classification systems for acoustic performance beyond the building code requirements (eg good better best).

Recommended Research

The following are suggested aspects of a research programme which can be used to initiate and implement post-construction and post-occupancy subjective and objective acoustic performance surveys in New Zealand.

6.2.2.1 COMPILING EXISTING INFORMATION

Summarise existing surveys and survey techniques from other countries. This would form the basis of a New Zealand survey and survey methodology. The COST TU0901 working group 2 developed questionnaire and survey methodology [33] and this could form the basis of a New Zealand survey methodology.

The latest information about international subjective and objective rating correlation research to note the latest challenges, concerns and research direction should also be compiled.

In addition, it needs to be determined whether there are any particular New Zealand requirements that are not considered in the overseas surveys and methodologies.

6.2.2.2 ESTABLISHING POST OCCUPANCY SURVEYS

Based on the information gathered previously, set up a survey methodology for regular subjective surveying of occupants and objective measurement surveying of completed and occupied constructions. A range of housing types and end uses would need to be included.

6.2.2.3 CORRELATING OBJECTIVE MEASURES WITH SUBJECTIVE SURVEY RESULTS

It is desirable to ensure that the existing single figure acoustic insulation rating systems and measurements used in New Zealand are acceptable, or whether they need to be changed or improved. For example, an on-going concern around the world is whether rating systems are suitable for all construction styles, in particular, whether heavyweight and lightweight constructions are treated equally by rating schema. In the case of floors, overseas research provides evidence that two rating criteria for impact insulation are needed (low-frequency and high frequency). How would such information be applied to the context of NZ living styles and construction methods which tend to be lightweight or midweight systems due to seismic constraints?

Having an on-going subjective/objective survey analysis which correlates acoustic ratings with subjective responses for different building types will provide more information regarding the suitability of acoustic ratings. This information would be useful for proposed building code changes or giving the construction industry more reliable objective metrics to gauge the acoustic performance of their buildings.

6.2.2.4 IMPROVING OBJECTIVE MEASUREMENT METHODS

For an objective measurement method to be useful it needs to be easy to use and give repeatable measurements. For example, it is quite common for measurements to be reported down to 50Hz in field tests, and in some cases in Europe for single figure ratings to also include such low-frequency measurements and beyond (to 20Hz). The uncertainty and reliability of these low-frequency measurements is not always clear or needs to be improved. It is important to know such uncertainty before adoption (e.g. Mahn and Pearse [34]).

We recommend that research be done to ensure that the most appropriate measurement methods are used in New Zealand for New Zealand construction methods, and are in step with international standards.

An example of an alternative test method – The Impact Ball was developed for use as an impact source for measurements of impact sound insulation performance – more effective than tapping machines at quantifying low frequency impact insulation. – used for ISO 16283 Field Measurement of impact sound insulation.
See http://www.campbell-associates.co.uk/impact-ball

Additional research could also consider ways to make the objective measurement process cheaper, perhaps by allowing lay-people to make in-situ measurements using smart measurement systems.

6.2.2.5 LISTENING TESTS

Listening tests performed using high quality auralisation systems (measurement and simulation based) are beginning to make significant headway in applications to test subjective response to building acoustic issues. Simulations of not only airborne transmission but also flanking and impact noise transmission can be performed. The advantage of such listening tests is that it is easier and cheaper to test different scenarios using essentially the same listening space. It is also possible for end users to experience the acoustics of a building which is yet to be built.

"It is clear the perfect link between results from acoustic measurement or from prediction models and finally results in single numbers is the technique of auralisation. It is the perfect carrier of information from the acoustic expert to the population, to local authorities and to politicians"- Vorlander, M [35]

Auralisation combines with virtual reality in a listening room
Image: Marshall Day Acoustics

There are a couple of listening test rooms and simulators available, or soon to be available, in New Zealand.

We recommend that research into using listening tests be explored in order to complement post-occupancy subjective surveys potentially making for more cost-effective results.

6.2.3 BUILDING SYSTEM SOLUTIONS AND TOOLS

When asked for specific acoustic R&D needs during the Stage 2 survey, there was a strong response from the construction industry that acoustically better building designs and solutions are an important area requiring further R&D. Producing better system designs and solutions in New Zealand consists of a number of aspects which can be addressed. These aspects range from design information and tools which enable the designer to produce effective designs, the ability to also easily incorporate knowledge from other design disciplines (such as fire safety, structural and energy efficiency requirements), improving existing, well-known designs solutions, and incorporating and adapting new technologies and products.

Recommended Research

We therefore recommend that work be done in the following areas to address the problem of better building design solutions for acoustic performance.

6.2.3.1 BUILDING SYSTEM ACOUSTIC PERFORMANCE INFORMATION

The survey revealed that data provided by manufacturers was the primary source of acoustic information used by designers of MDH. In particular, the GIB handbook [36] was extensively used, presumably because it includes a wide range of common elements and systems. It was also noted that information on the effect of combining different systems (e.g. the effect of junction details on flanking transmission) was difficult to obtain and that there were concerns over the perceived lack of independence of information provided by manufacturers.

An independent repository of information on the acoustic performance of a comprehensive range of building elements and systems would therefore be highly desirable. As noted in section 6.1.1, a key recommendation of this project is establishing an independently hosted web based “Quiet Housing” hub, which could provide a platform for access to such a repository.

Whole system performance: As the extent of the information available increases it is likely that a computer based tool could be developed. An example of such a tool is soundPATHS (www.nrc-cnrc.gc.ca/eng/solutions/advisory/soundpaths/index.html) which has been recently developed at the National Research Council of Canada (NRC), or others that are mentioned in Appendix E2.

SoundPATHS can be used to calculate the Apparent Sound Transmission Class between two rooms for a range of different wall and floor/ceiling structures made from a range of materials and incorporating a number of different junction types. Materials include CLT, Concrete, Concrete Block, Wood-Framing and Lightweight Steel. SoundPATHS also gives information on the relative importance of different sound paths in a structure which allows easy identification of design weak spots or elements where insulation could be reduced.

The calculation method used in soundPATHS follows the requirements of the National Building Code of Canada and as such results generated using soundPATHS can be used as evidence of compliance with that Code. The calculation method is described in a series of reports published by the NRC, e.g. [37]. The data used in the method was obtained from an extensive series of experiments undertaken at the NRC acoustical laboratories.

A tool similar to soundPATHS or a repository of information on the acoustic performance of such structures would be a valuable resource for New Zealand. The resource would provide industry with the necessary information to determine the acoustic performance of a complete building system. A single online repository would ensure information was independent, easily accessible and would include information on the acoustic performance of combined systems. However, the development of such a resource would require a large test programme and the storage and maintenance of the information. Incorporating data from overseas test programmes could be used to minimise the cost of its development.

BIM: A mention of integrating acoustic prediction tools into Building Information Modeling (BIM) was made in the survey. There is ongoing international R&D to upskill BIM software in order to implement building performance simulation right from the concept design phase. Energy efficiency and lighting simulation plug-in and built-in software components are already available in most of the mainstream BIM software. Some of BIM software have capabilities for acoustical analysis, but they are limited to noise level demonstration of Mechanical, Electrical and Plumbing (MEP) systems in buildings.

More sophisticated software specific for acoustic analysis can use data and models exported from BIM software to provide more precise simulations[38]. The integrating of acoustic simulation directly into BIM software has the potential to simplify and speed up the design process and reducing costs towards achieving acoustic performance of an indoor space[39]. However, the development of plug-in and/or built-in simulation tools for BIM software should be done in coordination with and potentially funded by BIM software houses who will benefit from licence fees and subscriptions.

6.2.3.2 INCORPORATING OTHER DISCIPLINES

Although we are considering acoustic insulation, the overarching goal is to provide the New Zealand construction industry with cohesive research and knowledge to enable better design and construction of multi-family dwellings. The buildings ought to be quieter, safer, more comfortable, more sustainable, more buildable and cost-effective.

Existing scientific and technological principles addressing acoustic comfort, structural safety, fire safety, energy efficiency and building physics performances requires effective integration in order to achieve effective performance levels in a cost-effective way. This has proven to be a challenge for both the design and construction industries.

Acoustic performance will need to be part of a multidisciplinary integrated research approach to produce effective solutions. To achieve this goal better methods need to be explored for multiple disciplines to seamlessly work together to produce integrated solutions. The disciplines to include are Acoustic Performance, Seismic and Structural Performance and Resilience, Fire Safety, Weather and Air Tightness, Durability, Thermal Performance, Sustainability, Buildability, Aesthetic Perception, and Cost.

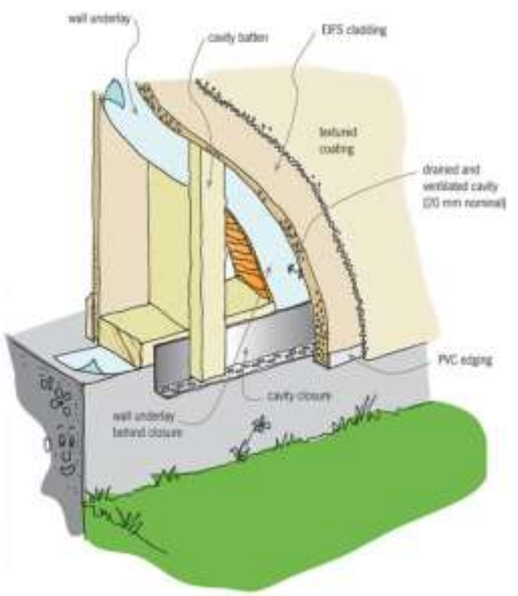
One particular concern of the construction industry as borne out from the survey was to ensure that solutions are cost-effective, easy to build (buildable), and are robust to defects. So it is important that these disciplines are also included in the multidisciplinary approach.

6.2.3.3 MODIFYING CURRENTLY-USED, COMMON DESIGNS FOR BETTER PERFORMANCE

In New Zealand, we currently use a number of common generic system and part system designs for intertenancy noise control. These systems are common because the building industry is setup to build these systems with existing knowhow and supply lines. In many cases these existing systems are not very effective and will struggle to reach the performance demands of future occupiers (and regulators). These existing systems may also have buildability issues and may not be very easy to build resulting in unintended defects which dramatically compromise the expected performance.

An example of such a system might be a light-weight joist floor with a resiliently attached ceiling. How can such a system be modified to improve the impact insulation performance? Do we need to add a floating floor to improve high-frequency performance? Do we need to add mass to the upper surface to improve low-frequency performance? Is there a simpler way to achieve both these aims?

Another example is the introduction of ventilated cavities and rigid insulation to exterior wall and roofs. Resonances caused by small cavities or foam style insulation has the potential to significantly affect the low frequency performance of the building envelope (e.g. traffic noise reduction). Testing and analysis of common wall and roof construction would facilitate cost effective solutions being developed.

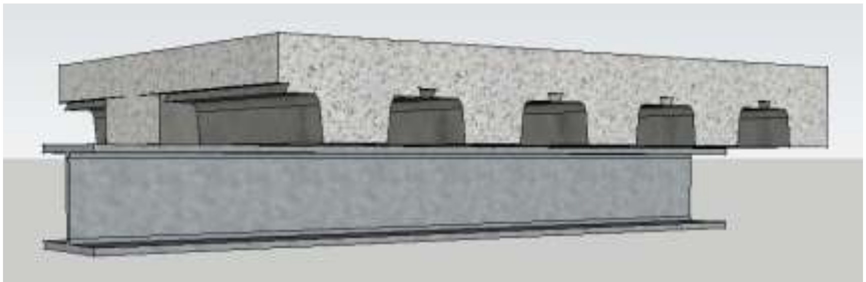


Example of ventilated cavity system Source BRANZ

Similarly, medium weight steel/concrete composite flooring systems are common for apartment buildings, but tend to have poorer acoustic performance than heavier concrete systems due to the reduced mass, increased stiffness and an unbroken composite nature.

Research projects looking at ways to improve and adapt commonly-used solutions already built in NZ to make them more effective (in a multidisciplinary way) would therefore be useful.

Composite concrete floor system - section: ***Source Marshall Day Acoustics***



6.2.3.4 NEW AND EMERGING PRODUCTS AND SYSTEMS

A number of new construction techniques and products are emerging in the New Zealand construction scene. Some of these technologies originate from New Zealand, and some technologies are being brought in from overseas. These systems may need to be further developed to provide acceptable and cost-effective acoustic insulation, or otherwise adapted to New Zealand conditions (such as additional seismic requirements).

Examples of systems that have extensive overseas development and are starting to be deployed in New Zealand include Cross Laminated Timber (CLT) constructions and Structural Insulation Panels (SIP).

One of the advantages of CLT is that individual CLT elements are custom manufactured in a factory and are then transported to the construction site where they are assembled precisely and relatively cheaply and quickly.

There has been a significant amount of work done recently to characterise the acoustical performance of CLT structures [40-44]. While the prediction methods appear to be promising, they are, however, reliant on empirical data which is expensive to collect. Further research to develop prediction methods which minimises the need for such data would be welcome.

There will no doubt be further new developments in materials and building solutions. Having mechanisms for the formal management of the data such as was described in the above section on "Building system acoustic performance information" or predictive methods such as those described there and in the following section would enable systematic validation of such materials and rapid uptake of their use. Research projects which look to enable better acoustic performance of these new systems for a reasonable cost, whilst retaining their current advantages such as reduced mass and ease of installation, would also be useful for the industry.

The development of products and materials would be part of this area of work. One would expect, however, that the development of building products should be funded by industry. The survey did note that some products which were marketed as having good acoustical performance were expensive and that installation errors could significantly affect acoustical performance, so there may be need to perform overarching research on some product types to make them more cost-effective and of benefit to all.

6.2.4 PREDICTION METHODS

The survey highlighted the need to consider acoustics very early in the design process, together with the need for tested and accredited solutions. While a database of such solutions can be populated by test results, supplemented by manufacturers' data and resources, accurate prediction methods are required, particularly for new and emerging materials, components, designs and constructions. In particular, due to the lightweight nature of structures in New Zealand, flanking transmission is of particular importance and is also difficult to predict using established methods. The development of improved methods of flanking noise prediction is thus required.

For monolithic structures EN-12354 [45, 46] provides a sound basis for the prediction of flanking transmission. It is based on a simplified Statistical Energy Analysis (SEA) approach in which, in effect, only interactions between nearest-neighbour subsystems are considered. However, for lightweight building structures the methods of EN 12354 are not applicable [47]. The reasons for this are various and include inhomogeneity of stud walls, double-leaf constructions etc, non-diffuseness/directionality of wave fields, periodicity of construction and high variance etc.

Recommended Research

It is recommended that a modified approach, along the lines described in EN 12354 but suitable for flanking transmission prediction in MDH, be developed. This should be able to incorporate additional detail and complexity in the SEA model, to allow for junction detailing, wall construction etc, into the prediction of sound reduction index. Prediction tools would allow for early assessment of the potential of new and emerging solutions and methods, while also allowing for optimisation of the design detail prior to the construction of prototypes for testing. Prediction results should be supplemented by a database of measurements. The contribution of non-resonant transmission should also be included.

There are various candidate approaches and the applicability and development for MDH applications should be critically evaluated, with the most promising approach developed further for application to lightweight structures. These and other methods were reviewed in section 5 of the Stage 1 report. What the most promising candidates have in common is a finite element (FE) model of the junction between subsystems to capture the full detail. The "Virtual SEA" method [48] post-processes a full FE model and has been applied to lightweight structures (e.g. [49], and contributions in the EU-based projects Silent Timber Build (http://silent-timber-build.com/) and HCLTP - Hybrid Cross Laminated Timber Plates (http://www.hcltp.com/). Other work has been focused on the aerospace and automotive industries (the original focus of [48]), although the physics should be applicable to MDH applications. These include the application of SEA to periodic structures [50], the prediction of energy transmission using FE models [51] and a hybrid FE/SEA method [52].

One final aspect should be the development of cost-effective software tools to allow for predictions to be made - commercial packages are often tailored for high value/high volume industries (e.g. automotive) and too costly for our purposes.

6.2.5 CONCLUSION

In response to the industry survey of Stage 2 we have made recommendations for research areas which we believe would be of benefit to the New Zealand building industry. In summary these recommendations are:

- **Subjective and objective post-occupancy surveys.** Such surveys will give feedback on the acoustic performance of particular construction designs, enabling verification of building design performance and input to regulation.
- **Enabling better building designs and solutions.** This includes developing acoustically better systems from existing construction design and adapting new systems for use in New Zealand. Also includes methods and tools to enable incorporation of performance requirements from other disciplines and to make the information readily available.
- **Developing better acoustic prediction tools**. This entails adoption and further development of prediction methods which are showing good promise as acoustic prediction tools for sound insulation.

6.3 USEFUL OVERSEAS SOLUTIONS

This section looks at some overseas solutions highlighted during our research - elements or ideas of which could be implemented in NZ – 1) Robust Details UK, 2) Dataholz.com, 3) Flooring solutions

6.3.1 ROBUST DETAILS UK

The Robust Details system introduced in the early 2000s in the UK is a whole framework aimed at helping create cost effective buildings that meet the acoustic requirements of UK building regulations 2010 Part E, and associated Approved Document E: Resistance to the passage of sound. In our survey, the UK Robust Details system was the main overseas solution consistently mentioned as being useful for adoption in NZ.

See Volume 2 Chapter 29 of [12] for a run down of the background to Robust Details, and www.robustdetails.com for full information. On registering with the website it is possible to download the complete Handbook for free. Note that the solutions included are to meet UK regulations and may not be directly applicable in a NZ setting.

It is more than just a list of solutions that if used comply with UK requirements, but addresses many of the points we discovered during our industry consultation (eg the desire for generic solution details, feedback for monitoring and improving performance, independent information provider, quick clear compliance pathway, education and training.)

In the UK prior to the introduction of Robust Details and mandatory testing in 2003, they discovered that although there were building requirements and standard solutions in the building code, there were significant complaints and random testing highlighted that a large proportion housing that were supposedly compliant were in fact not compliant. This highlighted the significance of flanking and construction errors, even when the building element design complies.

A new set of regulations and supporting documents were introduced in England in 2003 which again listed minimum criteria and standard construction information but for attached dwellings also required mandatory acoustic testing of a sample of finished constructions in each development. There was some resistance to this and also a shortage of testing providers to cover all new builds.

The Robust Details system was an industry led initiative introduced as a complementary compliance alternative, in response to the code changes and the difficulty and costs of large scale testing. The Robust Details system provides a handbook of fully tested and compliant generic and proprietary solutions which if registered as being used, in conjunction with relevant inspections and compliant monitoring signoffs could be certified as complying with UK Building Regulations E.

The system includes:

- A handbook of clearly defined construction details for use in standard housing configurations including full details of all junction details and flanking considerations.
- Is run through an independent non-profit organisation in close collaboration with the UK government, so it is seen as an independent, unbiased information provider.
- Building projects pay a minimal fee to register the use of a particular combination of details in a housing development with detailed inspection/construction checklists for each which must be signed off – this reduced the need for acoustic specialist design, testing and inspection in straightforward builds, while still encouraging good quality.
- Registration of the use of each Robust Detail enables feedback on any issues with the buildability, tested performance outcomes and post-occupancy complaints associated with that Robust Detail. A randomized sample are also tested to check ongoing performance. They now have a massive database of information of the details in use.

- A clear system of requirements and testing processes for adding additional generic solutions, (manufacturers can also say they meet or exceed the requirements of E-FT-3, generic timber floor three for example). There is also the option for proprietary systems to be added to the handbook.
- Before being added to the handbook, all solutions are extensively tested to ensure they well exceed code requirements, providing good tolerance to construction issues (on average 5 points above regulated minimum requirements). They must also provide good performance across the frequency range and have robust buildability.
- Robust Details also provide roadshows to raise awareness, education programs, and supporting videos for solution construction.

After 10 years the success of the system has been widely lauded in dramatically improving outcomes ([53] discusses the impact of regulatory changes in the UK up to 2014) with vastly improved compliance rates of builds using Robust Details to confirm compliance. Note there is also consideration underway in the UK for similar information in relation to Thermal requirements.

The Robust Details system was originally introduced in England/Wales which share similar regulations. It has recently been introduced in Scotland which has a similar population to NZ though much higher proportions of attached dwellings.

There are certainly clear advantages for adoption in NZ, but the size of the UK attached housing market is far greater than in NZ, not only in absolute terms but also of MDH in proportion to the total housing pool. The testing requirements for confirming details require implementing the construction in multiple buildings across multiple developments using different builders, with a minimum of 32 tested builds before solutions can be incorporated in the handbook.

Implementing a full Robust Details type system in NZ is probably unrealistic to support the current NZ MDH market, and would need careful economic assessment. However, it indicates that, for standard MDH builds, more prescriptive solutions with good supporting information and construction monitoring and feedback systems would be a good starting point for improvement.

6.3.2 DATAHOLZ.COM

As the volume of available information increases, the delivery of approved construction details in a handbook format can become unwieldy. A useful tool identified, that has its roots in Austria, is the online tool at www.Dataholz.com provided by the Association of the wood industry and Pro:Holz Austria. Austria has some of the highest regulated sound insulation requirements in Europe.

Dataholz.com provides an online tool for searching for and accessing datasheets of construction details for timber based constructions that meet acoustic, fire, and thermal requirements, with technical information available on materials, building elements and junctions, both using generic and proprietary products. In the Austrian setting, these datasheets can be used as part of compliance with Austrian regulations.

It is envisaged that the “Quiet Housing” hub could long term provide a suitable home for such a repository of NZ relevant materials information and details, perhaps with this type of front end for delivery of the datasheets for sample solutions. Since this type of tool could help cover multiple disciplines there is scope for such a tool to be part of a general MDH information hub, and help towards the integrated design information industry is looking for.

6.3.3 OVERSEAS FLOORING SOLUTIONS

Survey feedback indicated noise reduction through inter-tenancy floors was the area where more information would be most helpful (Survey q11).

As noted in section 5.2.2, houses in New Zealand have traditionally been built with carpet floor coverings. This has been carried through to multi-storey MDH design where carpet floors have been the default floor covering for common inter-tenancy systems – especially with lightweight structures. Where hard floor surfaces are required it is assumed that the required impact treatment will be achieved within an equivalent depth of the carpet (i.e. approximately 10 mm).

The impact performance of thin underlay systems is limited – especially at low frequencies. Therefore, this design philosophy, of treating the impact sound in the top 10 mm, severely inhibits the performance of lightweight floor systems. Hard floor finishes on lightweight floor/ceiling structures are often only marginally compliant. Some floor/ceiling systems are promoted as intertenancy systems without a tested hard floor finish option. The focus on thin impact treatment also limits the adoption of new products such as CLT and prevents the use of thin/composite concrete floor slabs.

It is common in NZ for services from one unit to run through the ceiling of the unit below. This creates issues in terms of noise from plumbing to neighbouring properties.

It is also noted that where the ceiling and floor covering are relied upon heavily for overall performance, changes to these in future refurbishments can cause disputes.

One solution to the above issues is the incorporation of a 'floating floor' system, as widely used overseas.

Acoustic floating floor systems consist of an upper floor layer resting on a resilient acoustic underlay or resilient components designed to prevent impact and airborne sound transmission into the structural subfloor and surrounding walls.

By disconnecting the upper layers of the floor system from the underneath structure and subfloor, floating flooring systems provide improved impact and airborne sound insulation.

There are different existing design strategies and commercially available products to create floating floors. Developing a cost effective floating floor system and how this integrates with New Zealand building practices is something that warrants further attention.

Floating flooring and flooring on floating rafts are achieved by building up layers of dry panels on resilient layers and underlays. These panels may be fixed together or attached to battens to form stable rafts which float on the resilient acoustic underlays. Multiple layers of panels and resilient materials can be used and can be laid in different positions depending on the design requirements and types of floor structure, for example, just below the floor finish, below the floor sheeting, above a screed or the building structure. Granular materials can also be included as a layer to add mass, and improve vibration damping.

Floating screeds are achieved by constructing a wet or dry floor screed over an acoustic resilient membrane or over thermal/acoustic insulating panels that isolate the screed from the floor structure. Wet screeds are made using different mixes of sand and cement, sand and gypsum or natural hydraulic lime. Dry floating flooring systems are achieved by laying one or more layers, depending on design requirements, of gypsum, gypsum-wood fibre or cement boards on an acoustic underlay, loose granular dry infill or thermal insulation panels. Dry floating flooring systems, as for floating wet screeds, increase the flooring system mass, thereby improving the low-frequency acoustic insulation

6.3.3.1 FLOATING FLOOR SYSTEM COMPONENTS

Acoustic Underlays and Insulation Panels

Acoustic underlays can be positioned under a screed to separate it from the floor structure (e.g. concrete slab/pre-cast panels, CLT panels or timber sheeting) effectively achieving a floating screed flooring system. Commercially available underlays are rubber, foam, felt, composite material (e.g. rubber and cork) or bio based (e.g. cork, wood fibre). They are designed to provide high resistance to compressive loads and load bearing performance. By remaining elastic they maintain sound isolation under compressive loads.

The disconnection of a screed from the building structure can also be achieved through panels of thermal insulating materials. This can also be the case for underfloor heating systems where the thermal mass screeds are thermally isolated from the surrounding structural elements hence floating.

Commercially available thermal insulating panels suitable for floating flooring applications are designed to provide high resistance to compressive loads and load bearing performance. Thermal/acoustic insulation panels are available from a range of synthetic and bio based materials including for example polystyrene, **polyurethane, and mineral, hemp** and wood fibre.

The selection of the proper insulating material and panel density needs to be done according to design requirements and positioning of the insulation panel within the floating flooring structure (e.g. above or below a screed, below floor finishing, infill between battens).

Granular materials

Granular infill materials can be included as a layer to add (e.g. on CLT and light timber structures) or reduce (e.g. on heavy concrete structures) mass and improve vibration damping in acoustic flooring systems. Granular infill materials are suitable for dry floor systems. Sand, light expanded clay, mineral based (e.g. calcium, pumice, volcanic scoria), cellular concrete, sand and saw dust mix, mineral coated wood chips are used as dry infill levelling.

Isolated acoustic batten

Floating floor on isolated acoustic battens are built by layering underfloor panels on top of wood battens isolated from the structural floor base (e.g. concrete slab/pre-cast panels, CLT panels or timber sheeting) by a layer of acoustic resilient material. The cavity between battens is usually filled with acoustic absorbing batts or panels. The surface finishing layer is mounted on top of the underfloor panels and the flooring system is disconnected from walls by a resilient flanking strip.

Appendix G, section G4.2 gives a practical case study on the use of a new batten and cradle type floating floor system in New Zealand with corresponding images.

6.3.3.2 ADVANTAGES AND DISADVANTAGES OF DRY AND WET FLOATING FLOORING SYSTEMS

Dry flooring systems

Advantages

- Suitable for both heavy and light weight construction
- Easy handling of components on site
- Quick assembly and immediate serviceability after construction
- No wet trades required, recycled and bio-based products available

Disadvantages

- Some products might not be suitable for all floor finishing layers: depending on design detailing the substrate might not achieve the stiffness required by the floor finish.
- Lower mass (compared to wet screeds) results in reduced sound insulation in the low frequency range, in particular in light timber structures

Wet screed flooring systems

Advantages

- Screeds can provide additional mass to the structure improving sound insulation in the low frequency range
- Screeds provide a suitable substrate for most floor finishes
- Screeds can incorporate building services such as electric, plumbing and under floor heating/cooling
- Screeds can potentially improve floor system thermal insulation (e.g. aerated-aggregate concrete)

Disadvantages

- Wet trade involved in constructing the screed, this requires on-site moisture management
- Extended curing time before serviceability after construction
- Additional mass can be problematic – especially for lightweight floor systems.

6.4 NZ BUILDING CODE

Actively assessing and updating Building Code requirements, to meet changing needs and standards, and adding additional acceptable solutions and guidance, are integral to the long term success of the Building Code. The research team strongly encourage continuing active assessment of Clause G6 since it acts as a primary driver for acoustical design in NZ for MDH.

When this research project was proposed, the expectation was that the latest 2016 proposed update to Clause G6 & G6 compliance document, would be going out for public consultation and approval around the start of this project. This update, as with the previous proposals, could have addressed some of the issues noted in this report and set a new bar for acoustic quality for the building industry to meet, along with providing a wider range of acceptable solutions (see Section 5.2.5.1 and Appendix D2.1 for more on G6 changes).

As this project comes to an end, it is apparent that the G6 update will probably not be going through for some time, certainly not until well after the next election, since the latest draft has not been approved even for release for wider consultation. It is likely that in the current climate of concern over the affordability of housing in NZ, any regulatory action which could be seen to increase housing costs is likely to be hard to promote without very good supporting information and a very clear cost benefit.

The original project proposal noted the research did not intending to replicate the work undertaken in determining necessary changes to G6, but being an assessment of broader requirements to help industry. However, in light of the G6 update not going through and the feedback from our research, we would still recommend that work to review and update G6 continues. Although any update to the building code is up to the government (MBIE), hopefully this research can help in the assessment of any change. It is hoped that the recommendations in relation to awareness raising and information dissemination, and seeking further evidence on end-user needs, should provide a firmer base and support for any future change.

7 CONCLUSIONS

The purpose of this research project was to identify the key acoustic issues affecting Medium Density Housing in New Zealand and develop a strategy for addressing them.

A survey of industry representatives showed that they were aware of the importance of acoustics in MDH but felt that the technical information currently available was insufficient to enable projects to be delivered effectively. The primary requirement was for resources that provided generic well co-ordinated design solutions in a format that is easy to access and follow.

The recommended mechanism to address this need is a web based 'hub' which would act as a focal point for technical information and support. Having the information readily accessible in modular form is recommended as this would enable it to be more easily updated and expanded.

A recent proposal to update the New Zealand Building Code Clause G6 is not likely to progress in the near future. It is recommended that the proposed 'hub' utilise much of the work undertaken as part of the proposed update with guidance documents developed on non-G6 related issues (i.e. not currently addressed in G6 but important to be considered).

The lack of NZ oriented technical information is limiting the adoption of new technologies. Further work is required to adapt overseas solutions to a NZ context (eg floating floors and CLT) and to provide more technical information on products and systems that are more common in NZ but not currently well understood (eg composite steel floors).

There is a lack of occupant surveys in New Zealand relating to acoustics. Incorporating occupant surveys and subjective testing into on-going research would help focus the priorities of the technical research and provide a basis for recommended design criteria going forward.

APPENDIX A REFERENCES

The following is a listing of all references cited throughout this report and in appendices A to E (with the exception of references for Appendix section E3.2 and E3.3 which are listed at the end of those sections)

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A2 List of image permissions

(MDA = Marshall Day Acoustics, MBIE – Ministry of Business, Innovation and Employment)

Section	Image info
Throughout	Logos for all participating organisations used with permission. MDA, BRANZ, Jasmax, Enovate, Scion, eCubed, University of Auckland
Throughout	"Towards Quiet Housing" Survey result tables and graphs produced by Tessa Phillips, MDA
Chapter 2 intro	Hobsonville apartments – image used with permission from Jalcon
	Flanking paths – drawn by Tessa Phillips, MDA
4.2	child holding ears – wikimedia commons with link
4.3	Quiet zone sign – wikimedia commons with link
4.4	INSUL Plot – produced by MDA
4.5	INSUL Plot – produced by MDA Tapping machine – photo by Tessa Phillips, MDA
5.2.2.6	Dwelling type graph – draw by Tessa Phillips, MDA Sound Level Meter – photo by Tessa Phillips, MDA
6.2.2.5	Aurelisation / listening room photo - MDA
6.2.3.3	Ventilated cavity graphic – BRANZ Composite floor graphic - MDA
C2.2	Flanking paths – drawn by Tessa Phillips, MDA
D2.3.1	Sound transmission Building code compliance diagram – MDA (needs colour)
D2.4.5	Section G6.3.4 from proposed Building code public consultation document – MBIE
D2.5.4	Table 1 from proposed Building code public consultation document - MBIE
E3.5.2 and E3.5.3	Map location plots produced by Grant Emms/Scion
Appendix F	Images from draft G6 proposed update 2016 used with permission from MBIE and a couple of extras by MDA.

APPENDIX B ORIGINAL PROJECT PROPOSAL

For reference, included below are the project objectives, outcome and methodology sections of the Proposal document submitted to BRANZ, in response to the requirements of the 2016/17 Building Research Levy Prospectus [1].

* The focus did change somewhat, to a more holistic approach rather than specific structural requirements, given the feedback received.

** Structural advice came primarily from Kirk Roberts during Stage 1 and Enovate from Stage 2

B1 Project objectives

The project would aim to:

Clarify the end user needs

- *Define acoustic 'quality' in the context of current and future legislation*
- *Identify any significant trends caused by occupier requirements or changes in the building environment*

Determine the extent and the type of knowledge required by designers and industry

- *Review current design guides*
- *Survey the results from recent research, both overseas and within NZ*
- *Identify the primary factors limiting the production of quality MDH for each of the major construction types – ie timber, steel and concrete. **
- *Highlight any conflicts between the acoustic requirements and other design constraints.*

Identify gaps in the current knowledge and prioritise theses gaps in the extent to which they are limiting production of quality MDH.

- *Propose methods of filling the knowledge gaps*
- *Determine the most effective means of presenting acoustic technical information to the industry*
- *Identify areas requiring further research Propose priorities for research based on current construction needs*
- *Propose specific research projects*

B2 Expected project outcome

This research project is considered to be the first stage in a programme whose ultimate outcome is to enable the cost-effective construction of acoustically comfortable buildings that are also durable, warm, dry, cost-effective and attractive to live in.

Enabling cost-effective construction of acoustically effective and comfortable MDH, will help ensure that MDH is a design option that is demanded and accepted by end users and stakeholders. This will enable councils in cities with larger populations to densify housing with less push-back from the general populace (occupiers and other stakeholders).

Direct outcomes from the projects will increase the level of knowledge of the key participants in the building industry: construction firms, local authorities, architects, structural engineers, building services engineers, acoustic engineers and manufacturers of building materials. The project will identify key areas for future research where current practice and design methods are deficient or absent and identify gaps and deficiencies in knowledge, data and codes.

B3 Describe your project methodology

The two primary issues associated with the acoustic performance of MDH are:

- *External noise – adequate protection from sources such as road traffic, aircraft, and other properties*
- *Internal noise – adequate provision of sound separation between tenancies*

The research project will look at both of these issues - operating in parallel streams. Although the fundamental questions in each of these areas may be different they are both significant considerations in many MDH developments. Designers and construction companies will be involved in both issues and by looking at the two issues together there is in efficiency in terms of research time and the relative priorities of the two issues can be better determined.

*The research team includes both designers (MDA, Jasmax and Kirk Roberts**) and research institutions (Scion and UoA). The strength of this combination is to ensure the research proposed and reviewed is both of a high standard and relevant to the end users. Although they do not form part of the formal research team, developers and contractors will be actively engaged through the process to ensure practical issues and cost/benefit analysis form a significant part of the considerations.*

The project would be staged in the following manner:

Stage 1 - Literature review and identification of performance criteria

Undertake a brief review of research on the internal quality in dwellings.

> *The research project is not intending to spend significant time on establishing a suitable level of acoustical quality. A large body of work was done in the preparation of proposed changes to Building Code Clause G6 and it is not intended to revisit this work. Important recent research findings and areas not covered by Clause G6 would be considered.*
>
> *Guidelines for thermal comfort would be included for reference. The clash between thermal comfort and external sound insulation is an issue that requires attention and would form key part part of this study.*
>
> *A preliminary investigation would be undertaken into criteria for floor vibration. This is currently an area of concern for commercial buildings and may become an issue in future residential developments.*

Review existing/proposed legislation

> *The existing Clause G6 of the building code would obviously provide an important benchmark for inter-tenancy sound transfer but has many deficiencies. The proposed Building Code Clause G6 represents the latest 'state of play' in regards to both intertenancy sound insulation and external noise issues. This will form a very important criterion for proposed research and it is anticipated that it will be the reference for acoustical 'quality'.*
>
> *However it is noted that the code may not make it to legislation and the proposed G6 includes upgraded performance in several areas.*
>
> *The control of external sound insulation is undertaken in a variety of ways by local councils. A review of typical examples for the main centres would be undertaken to ensure any short term actions would be directly applicable.*
>
> *How the conflict between thermal comfort and acoustic is dealt with by the Councils will require consideration.*

Acoustic and Construction Design Guides

The project will review current information available to designers and construction companies on the acoustic performance of MDH. The review will include commercial systems as well as more generic information.

Prominent overseas design guides will be investigated and their applicability to NZ conditions and criteria assessed.

State of the art review of research

A brief review of current research in research institutions, industry and academia will be undertaken as part of the initial stage. This will seek to identify recent advances in predictive techniques, the current areas of study, the goals of the research and future issues, together with recent advances in software tools.

The review of research will include an overview of research into modelling prediction and design methods with a focus on research concerning lightweight buildings, building acoustics and MDH. The purpose is to identify significant findings and methods that would be available to designer immediately or in the near future.

A more detailed investigation of current research would be undertaken in the later stages of the project once key target areas had been identified.

Stage 2 – Industry consultation

This stage will seek to identify the current state of acoustic knowledge within the industry. What additional knowledge is required and what are the most pressing issues within the industry that require additional attention. This would be undertaken in the following manner:

Interview/survey

A survey would be conducted with a range of industry representatives. This would seek to identify the extent of and access to acoustic information as well as highlight areas of concern. The preferences for knowledge methods (website vs written documents etc) will also be discussed.

It is expected that part of the initial survey would be a written/online survey.

Follow up in-person interviews with key representatives in each of the industry sectors. It is anticipated that a core group of industry representatives would be identified to enable further feedback and review later in the project.

Case studies

It is anticipated that in the areas of concern the extent of knowledge may vary significantly between construction types. It is also anticipated that design co-ordination will be a key factor in developing practical solutions.

Case studies, of real-world situations, are considered to be a suitable method of articulating the issues and highlighting areas where design co-ordination is required.

Stage 3 – Development of solutions

It is anticipated that stage 2 will identify several areas where additional knowledge is required by the industry. Stage 3 will seek to identify the most appropriate method of satisfying these needs.

Determine appropriate dissemination of existing knowledge

There may be some problems that can be solved by application of existing knowledge but the current knowledge may not be in a form that is easily accessible by industry.

More effective knowledge transfer methods will be proposed.

In some cases the knowledge may be sufficient in each of the individual design discipline but the approach between disciplines is not well co-ordinated and the knowledge across disciplines requires improvement. Methods of improving co-ordination of design information will be proposed.

Any innovative and practical solutions, developed as part of the case studies would be documented. Documenting these solutions as part of the research would be an immediate assistance to the industry.

Identification of overseas solutions

Adopting or modifying overseas solutions to the NZ environment may be significantly more effective in the short term than developing bespoke NZ solutions.

A wide variety of structural design approaches that could be used in NZ have sometimes not been well studied or their acoustical properties documented. Also, there are a number of overseas design approaches which might be readily adopted and perhaps with minimal work could be developed and deployed to the design community.

There are often products and systems that have been developed overseas but are not available in NZ. The adoption of such products may also be hindered by regulatory requirements – for example testing to alternative fire standards. Such products may only require minor modifications to be suitable for NZ conditions.

Identify further knowledge required

It is expected that the research will identify gaps and deficiencies in knowledge and methods and consequent areas of research that are required. These may involve an extension of research being done overseas or an adaptation of the research for the NZ environment.

It is expected that following the industry consultation the team would be able to prioritise research tasks and provide proposals for specific projects.

It is anticipated that a targeted literature review would be required in areas that have been identified as the highest priority to ensure the research proposed is not repeating already available information.

APPENDIX C ACOUSTICS AND NOISE CONTROL FUNDAMENTALS

This appendix contains sections with more in-depth information for reference including:

- C1 Fundamentals of acoustics
- C2 Noise control fundamentals
- C3 Glossaries

This information was collated during Stage 1, and provides some more in-depth than the summary in Chapter 4.

C1 Fundamentals of acoustics

To fully understand how to control noise, a basic understanding of the physical nature of sound is needed. What we call 'sound' is actually energy transmitted by small variations of pressure that travel through air (or other medium e.g. water) and are picked up by the ear or other listening device. The fluctuations are many orders of magnitude smaller and more rapid than those of atmospheric pressure changes. The sound pressure fluctuations can be produced by movements and vibration of the air from the movements of a source such as the human voice box or electric speaker, or from a vibrating surface induced into vibration for example by an impact.

There are numerous acoustic books providing fundamental concepts, the theoretical basis for noise control techniques and acoustic measurement systems. Examples include: Long's "Architectural Acoustics' [8], Harris's "Noise control in Buildings" [9] or "Woods Practical Guide to Noise Control" [54]. Appendix C3 includes glossaries of some terminology used in building acoustics and noise control. The design guides discussed in Appendix E also often include overviews of basic acoustic concepts.

Key points to note about sound when reading the following sections are:

Energy transmission

Pressure waves travelling from a source to the ear transmit energy. Sound power is measured in Watts, and is proportional to pressure squared. As sound radiates from a source the energy is dissipated. Sound intensity is a measure of the energy passing through a unit area per time, in watts/m2.

Sound pressure level in dB

The nonlinear response of the human ear means that doubling sound power does not correspond to a doubling of perceived volume. The human ear can detect pressure fluctuations with a wide range of sound intensity, from approximately 10^{-12} watts /m^2 (threshold of hearing) to beyond 10 watts /m^2 (intolerable and damaging) and tends to a logarithmic rather than linear response. Since power is related to pressure squared, a more practical representation of aural response is a decibel based measure called Sound Pressure Level (L_p)

$$L_p = 10\ log_{10}\left(\frac{p^2}{p_o^2}\right) = 20\ \ log_{10}\left(\frac{p}{p_o}\right)$$

where p is the sound pressure at a location in micropascals (μPa) and p_o is the reference pressure, with a standardised value of 20 μPa in air. Some general notes include:

- doubling/halving sound source power corresponds to approximately a 3db increase/decrease in sound pressure level.
- What we think of as volume or loudness, is a somewhat subjective measure, but in approximate terms volume is

perceived to double/halve for a sound pressure level increase/decrease of approximately 10dB. This corresponds to about 10 times the power.

- Combining two sounds is not as simple as arithmetically adding two dB sound pressure levels e.g. 55dB+ 58dB = 59.8dB.
- Sound pressure levels provide a useful measure of sound, for example for assessing ambient or traffic noise. As noted in the glossary in the Glossaries in Appendix C3 there are a variety of measures related to sound pressure level, usually identified by differing sub and superscripts that identify things like the frequency weightings system used, time, measurement averaging period e.g. $L'_{nT,w}$

dB examples

To get a feel for sound pressure levels in dB Table 1 shows some typical examples, and Table 2 shows perception of changes in dB level.

Table 1: Average sound pressure levels in some common environments. - Based on pg 11 of [54]

Sound Pressure Level in dB	Activity	Subjective description
0	Normal threshold of hearing	Very quiet
20	Background in TV or recording studio	
40	Whispered conversation at 1m, residential area at night outside,	Quiet
50	Conversational speech at 1m, general office	
60	Busy shop or restaurant	Noisy
70	Loud radio in domestic room	
80	Kerb of a busy street	
90	Heavy Lorry at 6m, construction site	Very noisy
100	Max level at underground train station platform, automatic lathe shop	
110	Sheet metal shop – hand grinding	
120	Ships engine room (full speed)	Intolerable without protection
130	Pneumatic riveting at operators position	
140	30m from military aircraft takeoff	

Table 2: Change in noise level

Change in Sound Level (dBA)	Subjective Reaction	Impact
1 – 2	Imperceptible change	Negligible/less than minor
3 – 4	Just perceptible change	Slight/Minor
5 – 8	Appreciable change	Noticeable
9 – 11	Doubling of loudness	Significant/ Substantial

Frequency

All vibrations (including sound) can be described by their frequency or spectrum of frequencies. Frequency is the number of cycles per second - unit Hz (Hertz)

Audible frequencies

The air pressure fluctuations audible to the human ear as sound are in the frequency range of approximately 20Hz to 20,000Hz (20kHz). For reference the lowest note A on a piano is 27.5Hz and the top A seven octaves higher is 3520Hz – one octave corresponds to a doubling of frequency.

Frequency bands

Acoustic measurements are usually made across bands of frequencies, usually in octave bands (eg 125 to 250Hz, 1000 to 2000Hz) or third octave bands (eg 125 to 160Hz), with results combined following various standards to produce single number measures of sound pressure levels in dB.

Sensitivity

The human ear is most sensitive to sounds in the mid range 500Hz to 6,000Hz with sensitivity dropping off at lower and higher frequencies. This means that for the same sound intensity, sounds in the middle of the audible frequency range appear louder.

Human speech is made up of unique combinations of frequencies with the lowest fundamental components around 100 Hz through to high frequency components up to around 3 or 4 kHz. Most sound insulation descriptors apply across this speech frequency range.

Measurement Weighting

Acoustic measurements, which usually average across frequency ranges, may incorporate a weighting curve to allow for the nonlinear response of the human ear at different frequencies. These weightings can be applied to machine measured levels to better approximate human perceptions of loudness. For example Sound pressure levels with an “A-weighing” are often referred to as dBA.

C2 Noise control fundamentals

Noise is defined by the Oxford English Dictionary as both

- *“A sound, especially one that is loud or unpleasant or that causes disturbance”*
- *And “A series or combination of loud, confused sounds, especially when causing disturbance.”*

And more generally, noise is referred to as unwanted sound. Noise control is about controlling and mitigating the effects of noise

C2.1 TRANSMISSION PATHS

Transmission of noise can be thought of as follows:

Figure 8: Simplified block diagram representing the transmission of noise from a sound source along one or more transmission paths to a listener

Noise control in residential builds focuses on reducing noise levels in habitable spaces to acceptable levels. This can be achieved by

- **Controlling the noise at the source**. Examples include setting limits on certain activities or at certain times, educating neighbours to be considerate, isolating a source from the building structure (eg washing machine on isolating pads)

- **Controlling noise along transmission paths** between the noise source and listener, by increasing the attenuation of sound. Examples include:
    - improving the sound insulation properties of walls, floors / ceilings, windows, doors
    - impeding sound transmission through structures by breaking up the transmission path e.g. using materials with different acoustic properties, dampening, isolators and expansion joints.
    - sealing air paths between source and listener,
    - suitable positioning and orientation of buildings to minimise noise control measures,
    - consideration of room layout
- **Control of noise at the listener.** Not an option in the residential context. Although in an industrial building earmuffs or earplugs might be appropriate, in a residence they are not!

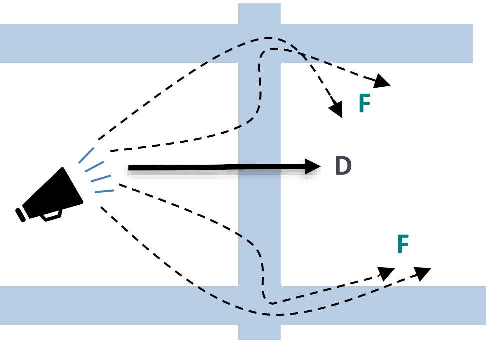
C2.2 NOISE SOURCES

The two key noise sources are airborne and impact.

1) **Airborne noise**: Sound sources, such as the human voice, stereo, TV, or musical instruments, produce sound pressure waves which radiate into the air. This sound can be transmitted between spaces via multiple paths, either directly via the air (for example through open windows, doors, air gaps, or ducting) or transmitted through building elements (such as walls, floors/ceilings, closed windows/doors).

The incident sound pressure waves stimulate the building element into very small amplitude vibration. Some sound energy is reflected back from the surface, some is absorbed and converted to heat, and some is transmitted through the element (or to connected structural elements through flanking transmission see Figure 9), with the resulting surface vibrations reradiating the sound at a reduced level.

Figure 9: FLANKING PATHS - Shows direct (D and solid arrow) and flanking paths (F and dotted arrows) in a building from an airborne sound source to receiving space. Based on Figure 1 of [10]



The sound reduction on the other side of the building element depends on the properties of the various transmission paths. .

Impact noise: When mechanical energy is delivered to a building's structure directly through impacts or vibration, the energy is transmitted through the structure and the resulting surface vibrations radiate as noise. The noise can be generated both on the surfaces of the building element to which the mechanical energy is directly delivered, or via transmission to other building elements through 'flanking paths'.
Examples of impact noise sources include: footfall; dropped objects; scrapping chairs; doors or drawers slamming; TVs / speakers /

appliances /pipes / HVAC equipment vibrating directly against a building element; hammering.

C2.3 SOUND ABSORPTION

Sound Absorption: The ability of a material to absorb sound. In doing so, the sound energy is converted to heat energy. Highly sound absorptive materials are useful within air cavities of double skin partitions as they prevent build-up of sound within the cavity and hence improve the acoustic performance of the building element. A measure of sound absorption is the Noise Reduction Coefficient (NRC). Efficient sound absorbers are typically made from glass wool, rock wool, polyester fibre, natural wool or cellulose fibre.

C2.4 SOUND INSULATION RATINGS

'Sound insulation' refers to the ability of a building element to limit noise transmission. There are various ways to assess the transmission of airborne and impact noise with various rating systems and measurement standards in use.

At a conceptual level transmission loss is a measure of the reduction in sound levels after sound passes through a building element. This is measured by comparing the sound level in a room with a sound source, to the sound level in another room separated by the element being tested and compensating for the properties of the rooms (size, reverberation time).

Although transmission loss varies depending on the frequency, in practice rating systems and measurements either consolidate the information to single figure ratings or ratings are presented for frequency bands. Although the detailed frequency response is lost, these metrics provide a quick way of assessing the acoustic performance of a building element. However it is important to understand that two elements with the same single figure rating may perform differently for different frequency sources.

These ratings tend to be the basis for specifying acoustic performance criteria in building codes.

Examples of sound insulation single figure ratings for a building element, for an airborne source are:

- ASTM standard: **STC (Sound transmission Class)**. Laboratory measured standard. To determine the STC rating of a building element, laboratory measured transmission loss values in the contiguous 16 one-third octave frequency bands between 125 hertz (Hz) and 4,000 Hz are compared with the values of an STC reference curve in a controlled test environment. See ASTM standards E413 and E336 [10],[55]
- ISO standards include **R_w (Weighted Sound Reduction Index).** Laboratory measured standard as defined in ISO717 Part 1, measured over the frequency range 100 to 3150Hz, and again compared with a reference curve. The ISO standards do allow for an additional correction factor e.g. C_{tr} to adjust for low frequency traffic noise,C_{tr} values typically range from about -4 to about -12. See ISO standard 717-1 [56]

In both cases, the higher the number, the higher the sound insulation. These single figure ratings can in broad terms be thought of as a frequency averaged transmission loss in dB, using slightly different averaging techniques. Both focus on the speech range of frequencies to ensure privacy, but give no indication of reduction at higher or lower frequencies

STC and R_w are ratings of the building element under ideal laboratory conditions. To test how the element performs in situ, where other factors such as flanking paths and actual installation play a part, field testing versions of these ratings are available.

- ASTM standard: FSTC (Field Sound Transmission Class). The 'field' or in situ measurement of Sound Transmission Class. Building tolerances and flanking noise have an effect on the performance of a building element when it is actually installed, which result in FSTC values lower than the laboratory derived STC values, typically up to 5 dB less. Strictly speaking flanking effects should be compensated for in FSTC calculations to provide a field measure the element itself, but the standard also defines ASTC (Apparent STC) which is more widely used in practice which includes the whole system effect via the partition and flanking paths. Ambient noise and various properties of the room are also accounted for in calculations.
- ISO standard $D_{nT,w}$ (Weighted Standardised Field Level Difference) It is a field measurement that relates to the R_w laboratory measurement, with the C correction terms also available. Again, the flanking paths and imperfect nature of in situ measurement lead to levels of typically 5dB lower than the equivalent R_w value for a building element.

Examples of single figure ratings for quantifying impact noise reduction include:

- ASTM standard: IIC (Impact Insulation Class) and the on-site equivalent FIIC (Field Impact Insulation Class). A single number system for quantifying the transmission loss due to impact noise produced by a standard "Tapper Machine" through a building element. The larger the number, the larger the reduction in sound. See ASTM standards E989 and E492 [57], [55]
- ISO Standards: $L_{n,w}$ (Weighted, Normalized Impact Sound Pressure Level). A single number rating of the impact sound insulation of a building element when impacted on by a standard 'tapper' machine. $L_{n,w}$ is measured in a laboratory. $L'_{nT,w}$ is the equivalent field measurement. The lower the $L_{n,w}$, the better the acoustic performance as this is a measure of how much sound energy reaches the receiving room from the standardised source on the other side of the building element. See ISO standard 717-2, [58]

Impact noise ratings tend to be used in regulations for floor/ceiling assemblies, testing impacts on the floor and how they carry though to the rooms below. However it can also apply to other elements such as walls, or rooms next door or diagonally below when the floor slab is shared.

C2.5 SOUND INSULATION TESTING

In order to produce single number ratings, materials and assembled building elements are tested at specialised acoustic testing centres that have the correct facilities to meet the relevant measurement standards specified for the rating calculation. In New Zealand the main testing centre is at the Acoustic Testing Service at Auckland University – see Section E3.5.2 for other centres internationally.

Material and building system manufacturers will usually get their items acoustically tested and product technical information sheets and manuals provide the single rating numbers (STC, R_w, IIC, $L_{n,w}$) so that designers can gauge the likely sound insulation performance. Although it is not possible to directly convert from one rating system to another, approximations can be made, and if the appropriate original test data is available (measurements over appropriate frequency ranges, and test space information) it may be possible to re-calculate the alternate rating.

C3 Glossaries

The following tables include glossaries of terminology used when considering acoustic design. (Marshall Day Acoustics)

C3.1 GENERAL SOUND TERMINOLOGY

Ambient	The ambient noise level is the noise level measured in the absence of the intrusive noise or the noise requiring control. Ambient noise levels are frequently measured to determine the situation prior to the addition of a new noise source.
Frequency	The number of pressure fluctuation cycles per second of a sound wave. Measured in units of Hertz (Hz).
Hertz (Hz)	Hertz is the unit of frequency. One hertz is one cycle per second. One thousand hertz is a kilohertz (kHz).
Masking Noise	Intentional background noise that is not disturbing, but due to its presence causes other unwanted noises to be less intelligible, noticeable and distracting.
Noise	A sound that is unwanted by, or distracting to, the receiver.
Octave Band	A range of frequencies where the highest frequency included is twice the lowest frequency. Octave bands are referred to by their logarithmic centre frequencies, these being 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz, and 16 kHz for the audible range of sound.

C3.2 SOUND EXPOSURE TERMINOLOGY

A-weighting	The process by which noise levels are corrected to account for the non-linear frequency response of the human ear.
dB	Decibel The unit of sound level. Expressed as a logarithmic ratio of sound pressure P relative to a reference pressure of Pr=20 μPa i.e. dB = 20 x log(P/Pr)
dBA	The unit of sound level which has its frequency characteristics modified by a filter (A-weighted) so as to more closely approximate the frequency bias of the human ear.
$L_{A10\,(t)}$	The A-weighted noise level equalled or exceeded for 10% of the measurement period. This is commonly referred to as the average maximum noise level. The suffix "t" represents the time period to which the noise level relates, e.g. (8 h) would represent a period of 8 hours, (15 min) would represent a period of 15 minutes and (2200-0700) would represent a measurement time between 10 pm and 7 am.
$L_{A90\,(t)}$	The A-weighted noise level equalled or exceeded for 90% of the measurement period. This is commonly referred to as the background noise level.

	The suffix "t" represents the time period to which the noise level relates, e.g. (8 h) would represent a period of 8 hours, (15 min) would represent a period of 15 minutes and (2200-0700) would represent a measurement time between 10 pm and 7 am.
$L_{A95\,(t)}$	The A-weighted noise level equalled or exceeded for 95% of the measurement period. This is commonly referred to as the background noise level. The suffix "t" represents the time period to which the noise level relates, e.g. (8 h) would represent a period of 8 hours, (15 min) would represent a period of 15 minutes and (2200-0700) would represent a measurement time between 10 pm and 7 am.
$L_{Aeq\,(t)}$	The equivalent continuous (time-averaged) A-weighted sound level. This is commonly referred to as the average noise level. The suffix "t" represents the time period to which the noise level relates, e.g. (8 h) would represent a period of 8 hours, (15 min) would represent a period of 15 minutes and (2200-0700) would represent a measurement time between 10 pm and 7 am.
L_{Amax}	The A-weighted maximum noise level. The highest noise level which occurs during the measurement period.
L_{den}	The day evening night noise level which is calculated from the 24 hour L_{Aeq} with a 5 decibel penalty applied to the evening (1800-2200 hours) L_{Aeq} and a 10 decibel penalty applied to the night-time (2200-0700 hours) L_{Aeq}.
L_{dn}	The day night noise level which is calculated from the 24 hour L_{Aeq} with a 10 dB penalty applied to the night-time (2200-0700 hours) L_{Aeq}.
SPL or L_P	Sound Pressure Level A logarithmic ratio of a sound pressure measured at distance, relative to the threshold of hearing (20 µPa RMS) and expressed in decibels.
SWL or L_W	Sound Power Level A logarithmic ratio of the acoustic power output of a source relative to 10^{-12} watts and expressed in decibels. Sound power level is calculated from measured sound pressure levels and represents the level of total sound power radiated by a sound source.

C3.3 SOUND TRANSMISSION, INSULATION AND MEASUREMENT TERMINOLOGY

Term	Description
C	A sound insulation adjustment, commonly used with R_w and $D_{nT,w}$. C adjusts for sources of mid-high frequency noise sources generated by typical living activities such as talking, music, radio, TV, children playing, etc. This term is used to provide information about the acoustic performance at different frequencies, as part of a single number rating system.
C_i	An impact sound insulation adjustment (spectrum adaptation term) for footfall noise. Commonly used with $L_{n,w}$ and $L'_{nT,w}$. This term is used to provide

Term	Description
	information about the acoustic performance at different frequencies, as part of a single number rating system.
C_{tr}	A sound insulation adjustment, commonly used with R_w and $D_{nT,w}$. C_{tr} adjusts for low frequency noise, like noise from trucks and subwoofers. C_{tr} values typically range from about -4 to about -12. This term is used to provide information about the acoustic performance at different frequencies, as part of a single number rating system.
$D_{nT,w}$	Weighted Standardised Level Difference A single number rating of the sound level difference between two rooms. $D_{nT,w}$ is typically used to measure the on-site sound insulation performance of a building element such as a wall, floor or ceiling
FIIC	The 'field' or in situ measurement of Impact Insulation Class. Building tolerances and flanking noise have an effect on the performance of a partition when it is actually installed, which result in FIIC values lower than the laboratory derived IIC values, typically 5 dB less.
Flanking Transmission	Transmission of sound energy through paths adjacent to the building element being considered. For example, sound may be transmitted around a wall by travelling up into the ceiling space and then down into the adjacent room.
FSTC	The 'field' or in situ measurement of Sound Transmission Class. Building tolerances and flanking

Term	Description
	noise have an effect on the performance of a partition when it is actually installed, which result in FSTC values lower than the laboratory derived STC values, typically 5 dB less.
IIC	Impact Insulation Class A single number system for quantifying the transmission loss due to impact noise produced by a standard "Tapper Machine" through a building element.
Impact sound	Sound produced by an object impacting directly on a building structure, such as footfall noise or chairs scrapping on a floor.
$L'_{nT,w}$	Weighted, Standardised Impact Sound Pressure Level A single number rating of the impact sound insulation of a floor/ceiling when impacted on by a standard 'tapper' machine. $L'_{nT,w}$ is measured on site. The lower the $L'_{nT,w}$, the better the acoustic performance.
$L_{n,w}$	Weighted, Normalized Impact Sound Pressure Level A single number rating of the impact sound insulation of a floor/ceiling when impacted on by a standard 'tapper' machine. $L_{n,w}$ is measured in a laboratory. The lower the $L_{n,w}$, the better the acoustic performance.
R'_w	Apparent Weighted Sound Reduction Index Similar to the Rw value except that measurements are conducted in the field. Building tolerances and flanking noise have an effect on the performance of a partition when it is actually installed, which result in R'_w values lower than the laboratory derived Rw values.

Term	Description
R_w	Weighted Sound Reduction Index A single number rating of the sound insulation performance of a specific building element. Rw is measured in a laboratory. Rw is commonly used by manufacturers to describe the sound insulation performance of building elements such as plasterboard and concrete.
Sound Insulation	When sound hits a surface, some of the sound energy travels through the material. 'Sound insulation' refers to ability of a material to stop sound travelling through it.
Sound Isolation	Complete acoustical separation between two spaces such that there is no sound transmitted from one to another.
STC	Sound Transmission Class A single number system for quantifying the transmission loss through a building element. STC is based upon typical speech and domestic noises, and thus is most applicable to these areas. STC of a building element is measured in approved testing laboratories under ideal conditions.
Structure-Borne Transmission	The transmission of sound from one space to another through the structure of a building.
Transmission Loss (TL)	The attenuation of sound pressure brought about by a building construction. Transmission loss is specified at each octave or one third octave frequency band.

APPENDIX D FACTORS INFLUENCING INTERNAL ACOUSTIC QUALITY IN NZ MDH

This appendix contains background and in-depth information on factors that influence internal acoustic quality in medium density housing (MDH) in New Zealand (NZ).

This was primarily collected during the Stage 1 literature review phase of the project, and is an amended version of information provided in the Stage 1 report. The main body of this report addresses key issues and information needs at a broader level, but it is important that the detail in this appendix is available in support of this overview.

Cited references are listed in Appendix A

D1 Introduction

For MDH to be widely accepted as a housing option in NZ, it is important that noise control methods are incorporated in the design of NZ MDH, and acoustic considerations are also included at both the urban and site planning stage. For the purposes of this appendix the focus is on the internal areas of a dwelling rather than external spaces such as balconies, gardens or courtyards, unless otherwise specified.

Acoustic design for residential housing aims to minimise the impact of noise and ensure that residents feel:

- noise generated outside the residence is perceived inside the residence at sound levels that do not cause annoyance
- that satisfactory privacy levels are maintained between residences and within a residence

In other words, ensuring that residents have a good level of "acoustic comfort" in their internal environment.

One problem for defining levels of acoustic quality is that acoustic comfort is highly individual and therefore a subjective quantity. Some individuals tolerate much higher noise levels than others. For example, perceptions of sound and loudness can depend on personal experience, the type of noise, frequency characteristics of the noise, noise sensitivity and hearing levels, and even expectations of the space. (Chapter 1 of [9])

However international studies demonstrate that it is possible to establish standards and building codes which, if a building meets those base standards, will provide acceptable acoustic comfort for the majority of residents [59]. Building codes are commonly used as the benchmark for acoustic quality. The percentage of happy residents will obviously be higher if higher standards are adopted. However, achieving higher levels of acoustic quality usually involves additional cost, so building codes have to balance economic factors with providing sufficient levels of resident satisfaction when setting these benchmarks.

> (Appendix E3.4 looks more closely at current research on subjective measures and their relationship to objective measurements used in building regulations.)

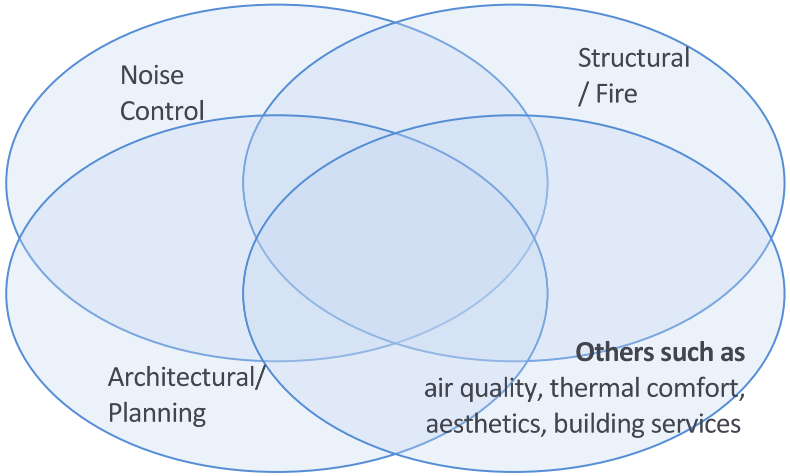
Even with a relatively high standard of sound insulation a percentage of people are likely to find the environment less than satisfactory. Perceived acoustic comfort within the homes will be a result of objective sound insulation performance, the behaviour of adjacent occupants and occupier expectations and reactions.

This section is separated into two main subsections.

- **Noise control**: This section gives an overview of different types of noise control requirements in typical MDH and how acoustic quality and performance is defined in the NZ context through current and planned legislation, district plans and standards. This includes overviews for inter-tenancy noise (both airborne and impact noise), environmental noise, building services noise, and rain noise. Also broad differences between the noise control component of NZ and overseas building codes are noted in terms of areas addressed.

- **Related factors**: The requirements for a good level of acoustic quality can in some cases conflict with other building design requirements, while other aspects may be complimentary. This section aims to highlight some of the interplay between acoustic and other aspects of MDH design including: ventilation and thermal requirements, structural requirements (including seismic and wind loading), fire compliance, lighting / glazing, water-tightness, economic, and regulatory requirements for other MDH design factors. Some design choices may also generate unexpected acoustic issues, for example wind noise through louvres or hum from wind induced vibrations. See Figure 10

Figure 10: Venn diagram demonstrating the overlap of requirements for various aspects of MDH design. MDA



Acoustic design for medium density housing (MDH) requires identifying solutions in the overlap between noise control requirements and other factors in MDH design.

D2 NOISE CONTROL

The purpose of this section is to outline core noise control considerations for MDH, how they impact the acoustic outcomes, and the performance criteria used and needed in NZ. First up discussion on the NZ Building Code as the key source of performance criteria, and then detailed consideration of various aspects of noise control in NZ MDH.

Note that in Australia, to complement their Building Code requirements, a non-mandatory Australian building code "Handbook for Sound insulation" http://www.abcb.gov.au/-/media/Files/Resources/Education-Training/Handbook-sound-insulation.pdf, is provided for reference by those applying the code [60]. It covers many of the same principals and general concepts of sound insulation as this section, (along with compliance methods in Australia though not technical criteria), and makes useful additional reading to this section and Appendix C.

D2.1 NZ BUILDING CODE PERFORMANCE CRITERIA

D2.1.1 CLAUSE G6

In New Zealand the Building Act 2004, Building Regulations (1992) and Building Code provide the framework for ensuring NZ buildings are safe and healthy to use. Specifications in the Building code provide minimum standard for all building work. For full information see the Building Code Handbook provided by MBIE (Ministry of Business, Innovation and Employment), and currently available for downloadable from their Building Performance website. [23].

Clause G6 of the building code is the currently adopted minimum acoustic performance criteria for 'abutting' residential housing in NZ, and has remained unchanged since 1992. Because of its importance for any discussion on residential acoustic design in NZ the current G6 clause is reprinted here in full in Figure 11.

The Clause is also supported by the associated compliance document "Compliance Document for New Zealand Building Code Clause G6 Airborne and Impact Sound" also available through MBIE's Building Performance website [5] and last minorly amended in 1995. This document clarifies that:

Building element is defined as *"Any structural and non-structural component or assembly incorporated into or associated with a building. Included are fixtures, services, drains, permanent mechanical installations for access [e.g. lifts], glazing, partitions, ceilings and temporary supports"*

Habitable space is defined as *"A space used for activities normally associated with domestic living, but excludes any bathroom, laundry, water-closet, pantry, walk-in wardrobe, corridor, hallway, lobby, clothes-drying room, or other space of a specialised nature occupied neither frequently nor for extended periods."*

Household unit is defined as *"any building or group of buildings or part of any building or group of buildings, used or intended to be used solely or principally for residential purposes and occupied or intended to be occupied exclusively as the home or residence of not more than one household; but does not include a hostel or boarding-house or other specialised accommodation."*

The versions of the standards referenced are ASTM E:336:1990, ASTM E 413:1987, ASTM E492:1990, ASTM E989:1989, ISO 140/VII: 1978 - All these standards have had updates since the 1992 G6 Clause and 1995 compliance document were written.

Figure 11: NZ Building Code Clause G6 [5]

Clause G6—Airborne and impact sound

Provisions

Objective

G6.1

The objective of this provision is to safeguard people from illness or loss of *amenity* as a result of undue noise being transmitted between abutting occupancies.

Functional requirement

G6.2

Building elements which are common between occupancies, shall be constructed to prevent undue noise transmission from other occupancies or common spaces, to the *habitable spaces* of *household units*.

Performance

G6.3.1

The *Sound Transmission Class* of walls, floors and ceilings, shall be no less than 55.

G6.3.2

The *Impact Insulation Class* of floors shall be no less than 55.

D2.1.2 VERIFICATION METHODS

The Clause G6 Compliance Document [5] includes verification methods for clauses G6.3.1 and G6.3.2 as follows in Figure 12

Figure 12: Clause G6 Verification Method [5]

Verification Method G6/VM1

1.0 Airborne Sound Insulation Field Tests

1.0.1 The performance for airborne sound insulation may be verified using the procedures detailed in ASTM E 336, and the field sound transmission class may be verified using the method described in ASTM E 413. Field test results shall be within 5dB of the performance requirement.

2.0 Impact Sound Insulation Field Tests

2.0.1 The performance for impact sound insulation may be verified using the procedures detailed in ISO 140: Part VII, and the field impact insulation class may be verified using the method described in ASTM E 989. Field test results shall be within 5dB of the performance requirement.

In other words once a building is completed, measurements can be made of the onsite performance of common walls, floors and ceilings between habitable spaces, to ensure they meet the building code requirements.

The measured FSTC values for walls, floors and ceilings should be no more than 5dB less than the sound transmission class requirement of STC55 ie FSTC no less than 50. The measurements of FSTC in strict accordance with the standard requires quantification / suppression of the flanking transmission via other elements to determine the field performance of the element alone. The latest versions of the ASTM E336 standard differentiates between Apparent Sound Transmission Class (ASTC) which includes flanking transmission and FSTC in which flanking is suppressed. ASTC was not defined at the time of the Building Code coming into operation and it is general practice in NZ to measure and assess STC with flanking paths included. ASTC will always be less than FSTC, so a compliant ASTC value ensures the FSTC value is met.

Similarly, the measurement of FIIC for floors should be within 5db of the impact insulation class requirement IIC 55. Ie FIIC > 50

D2.1.3 ACCEPTABLE SOLUTIONS AND ALTERNATIVE SOLUTIONS

The Clause G6 compliance document [5] also indicates "Acceptable Solutions". This includes examples of solutions (eg wall, floor/ceiling and junction construction details) that if installed properly should meet the building code requirements without requiring field measurements for verification.

Another path to compliance is Alternative solutions(see Building Code handbook[23]) – when neither the verification method or acceptable solution is used sufficient information must be presented to confirm the performance standard has been met.

D2.1.4 DETERMINATIONS OF THE BUILDING CODE CLAUSE G6 REQUIREMENTS

The Ministry of Business, Innovation and Employment have provided several recent determinations in relation to the application of the Building Code in relation to Clause G6. The following sections summarise the conclusions of these determinations. https://www.building.govt.nz/resolving-problems/resolution-options/determinations/determinations-issued/

1) Multi-Unit Buildings: Determination 2012/070

This determination concludes that while a single building containing several units may be under the same title, if the units function as independent households, i.e. they share no habitable spaces, then the building must be assessed as a multi-unit dwelling.

Therefore, compliance is determined by the provisions of the Building Code as they apply to a multi-unit dwelling.

2) Apartment Doors: Determination 2015/004

This determination concludes that entrance doors to apartments, i.e. door leading into an apartment from a common space, is not required to satisfy the performance requirements of Clause G6.

3) Specialist Accommodation: Determination 2015/004

This determination concludes that specialist accommodation only includes hostels and boarding houses. As such, retirement village apartments are considered household units and are required to achieve the provisions of the Building Code.

4) Horizontal Impact Transmission: Determination 2015/007

This determination concludes that impact sound insulation does not apply horizontally and only applies vertically where apartments share common building elements. Testing of impact sound transmission diagonally vertically across the line of an inter-tenancy wall is therefore not applicable.

D2.1.5 SUMMARY OF CURRENT BUILDING CODE REQUIREMENTS

Clause G6 of the NZ Building Code

- requires that noise transfer from any part of a household unit to a habitable space of another household unit is controlled to achieve

the following performance requirements for shared building elements:
- Airborne sound insulation performance for walls, ceiling and floors of not less than STC 55 / FSTC 50
- Impact sound insulation performance for floors of not less than IIC 55 / FIIC 50

- applies for household units with shared building elements (eg terrace/apartment). Multi-unit dwellings where there are no shared habitable spaces, regardless of unit title arrangement, *are* required to comply with the Building Code Clause G6 (eg retirement village apartments.
- Horizontally transmitted impact sound is not required to comply with the Building Code Clause G6. Diagonally vertically transmitted impact sound across an inter-tenancy wall is not required to comply with the Building Code Clause G6
- Diagonally vertically transmitted impact sound from one apartment located above another apartment must comply with the Building Code Clause G6, e.g. from a bathroom to a living room or a deck to a bedroom.

D2.1.6 NOT COVERED IN THE NZ BUILDING CODE

There are <u>no provisions</u> in the current NZ Building Code with respect to:

- Noise from external sources e.g. environmental noise – the building envelope (façade and roof) is not addressed directly in the building code, with sound insulation performance criteria set through a variety of different district plans across the country, all with slightly different approaches. See Section D2.4 for a full discussion on external noise control, and D2.7 for rain noise.
- Noise from supply and waste water plumbing, and mechanical equipment such as HVAC, garage doors or elevators –Section D2.5 looks at the control of building services noise.
- Performance criteria for noise from common spaces such as corridors, courtyards or lobbies, carparks – this is a grey area with wording within the current code – as identified in determination 2015/004 where common spaces are not strictly speaking determined to be occupancies. For more on this see Section D2.2 and D2.3 (Inter-tenancy sound insulation and IT impact noise)
- Noise transmission through walls within a residence (see note in Section D2.2
- Noise from occupied spaces that do not directly adjoin the household unit including from flanking paths such as pipes or diagonally across inter-tenancy junctions. See sections D2.2 to D2.5
- Building movement noises.

Note there are also no noise control requirements specified in the building code for detached single dwellings.

D2.1.7 PROPOSED UPDATE TO CLAUSE G6

As noted in the project proposal, an update to the G6 clause has been in consideration since the late 1990s. The most recent proposed update to Clause G6 was sent out for public submission in 2010, [24], but has not been adopted. The proposed updates have aimed to broaden the coverage of the clause, as well as raise the minimum standards. The title of Clause G6 is likely to change from “Airborne and Impact Sound” to something like ”Protection from noise” to better convey the purpose of the clause.

As noted in research papers during the development of a new Clause G6 (eg [27]) the current performance criteria put the NZ Building code near the lower end, relative to the building codes in Europe. Even where sound insulation and impact criteria are comparable or higher, other factors addressed elsewhere are not addressed in the NZ building code.

There is quite a bit of research on subjective responses to various ratings in Europe (see Section E3.4 for more on recent research on subjective responses).

However, in NZ there is limited direct research on noise control satisfaction levels amongst MDH residents in NZ. Although a number of general apartment surveys have been conducted such as [19] and [61] these generally only include one or two general questions such as general annoyance by noise. For example the Wellington City Council survey [19] noted "the most common negative aspect of apartment living was 'city noise and noise from neighbours' (27%)". At this point the team has identified few NZ surveys detailing responses relative to the building construction type, standard built to and external noise environment. One exception is the CRESA Study for CCANZ [62] which looked at differences between post occupancy results for high mass and light weight building constructions.

Cultural norms may mean that overseas studies are not directly applicable. For example, kiwis that have grown up in standalone well separated houses, will not be used to hearing voices, noise and movements from an adjacent apartments. They may previously not have had to worry too much about the everyday noise they make in their own home, and might take some adjustment to being more considerate neighbours.

However, there is sufficient evidence from European studies to indicate that the levels within the NZ code are likely to lead dissatisfaction with noise control from a significant portion of residents and the code minimum levels could certainly be increased and expanded upon. For example even with sound insulation at R'_w = 56dB (well above FSTC 50), Rindel's analysis [63] found about 20% of residents found the sound insulation to be poor, 30% fair and 50% good with the poor % increasing predictably with decreased sound insulation.

In communications with MBIE it is understood that a draft new proposed update is almost ready to go out for public submission, but as yet is not publicly available. The core members of the project team have access to a draft but as this is not publicly available and cannot make direct reference to it and instead refer to the publicly available 2010 proposed update [24]. It had been hoped that the new G6 could form the basis for an improved baseline for acoustic performance criteria. At this time, it is not clear if this will be the case within the timeframe of this project. *[This was written during Stage 1 of the project, with the proposal not going ahead at the time of project completion]*

It is hoped that even if this 2016 proposed G6 update is not adopted, that the option to provide the information for guidance is taken. This should help those wishing to develop MDH to a higher standard than set out in the existing code.

In Sections D2.2 to D2.9 aspects of noise control relevant to MDH are addressed, how they are covered in the building code or other regulations and a broad outline of the improvements sought in proposed updates.

Note: a common feature within proposed updates to Clause G6 is the proposal to shift metrics from the American based ASTM standards STC and IIC, to the internationally adopted ISO Standards. This makes sense since New Zealand has input to ISO standards. The 2010 proposed update notes the reasoning [24]:

> *The ISO metrics contribute to improved acoustic conditions because they measure actual room conditions rather than having an "allowance" to account for material and construction tolerances. They also measure to a third octave lower frequency band, thus including some of the low frequency energy that causes much dissatisfaction.*

While the proposed metrics appear more complex, both systems use single figure numbers that are derived from a series of specified measurements over the defined frequency band. ISO metrics are already used throughout the acoustics profession in New Zealand and the industry is well used to the terminology and methodology. This proposal will complement the common language already in use.

The ISO systems provide a series of spectrum adaptation terms (SAT) that allow the base measure, for example $D_{nT,w}$, to be tailored to address noise problems with specific frequency characteristics. These terms could be readily added later, if experience showed it to be necessary. [eg C_{tr}]

D2.2 INTER-TENANCY (IT) SOUND INSULATION

Airborne noise from neighbours includes voices, TV, music, dogs barking, and miscellaneous machine noises across a range of frequencies. It is important for residents' comfort to be protected from their neighbours' noise whether it comes through the walls, floors or ceilings either from other household units or the common spaces such as corridors and stairs. Higher acoustic performance standards are expected for inter-tenancy* building elements (e.g. common walls, floors, ceilings) than for those within a dwelling.

* In a building with separate housing units connected by common building elements, the adjective 'inter-tenancy' (often abbreviated to IT) is often used to refer to this connection.

This section focuses on the measurement and performance criteria for IT sound insulation.

D2.2.1 INTRODUCTION AND CURRENT BUILDING CODE REQUIREMENTS

The construction details for IT walls and floor/ceiling elements need to exceed the minimum NZ Building Code requirement as outlined in D2.1, namely that building elements which are common between another occupancy and a habitable space of a household unit have the following minimum performance: STC 55 / FSTC 50

Acceptable Solutions are listed in the current NZ Building Code Compliance document [5], however these are not typically used and in practice do not provide sufficient detail to develop a compliant design.

Product and system manufacturers usually provide STC and/or R_w ratings for tested building elements (e.g. an IT wall system, or flooring system), in technical information manuals or online (e.g. Gib noise systems, Speedwall IT walls). When built, the performance is reduced due to transmission between elements and it is critical that junction design is carefully considered to reduce flanking paths. Construction errors may also contribute.

Acoustic engineers are typically engaged to assess the overall design and recommend appropriate treatment. In Auckland, a Producer Statement (PS1) from a qualified acoustic professional is required to certify that the proposed design will achieve compliance.

Further confirmation of compliance with the building code is often required at completion of the project. Field measurements can be undertaken of a representative sample of elements as outlined in the Verification Methods section of the compliance document [5]. A Construction Review Producer Statement (PS4) is often requested by Council to confirm compliance.

It should be noted that there is not a consistent approach across NZ in the enforcement of G6 compliance. In particular, some Councils do not require acoustic testing and rely on the design being developed and executed correctly.

D2.2.2 PROPOSED CHANGES TO CLAUSE G6

There are a number of areas related to inter-tenancy sound insulation that are proposed to change to meet some of the shortfalls of the current code regarding both minimum performance standards and where the code applies.

The current building code uses the ASTM laboratory based STC rating, with the related compliance document referring to the field test equivalent (FSTC) being accepted at lower levels. The idea is for the new version of the building code to directly include the field performance requirement, in this case $D_{nT,w}$ (Weighted standardised field level difference) as the performance criteria to be met. This means the partition itself but also all flanking paths that transmit to the receiving room are accounted for.

The current building code is somewhat unclear about the requirements of walls between habitable units and common areas such as hallways and lobbies as although there is mention of common areas in the functional requirement, all references for performance relate to common building elements between occupancies. The proposed code aims to better quantify required levels in different circumstances – e.g. noise reductions seen in habitable parts of a household unit from noise in corridors, stairs, lobbies, carparks, or common services area.

Some apartments may be built that connect to other types of occupancies, for example an apartment above shops or commercial offices. The aim is to clarify provision and requirements for all types of connection.

Another aim is to include a greater range of Acceptable Solutions to aid with design. One goal at stage two of this project is to determine the industry preferences in relation to using Acceptable Solutions versus relying on testing of the end result.

D2.2.3 INTERNAL VERSUS INTER-TENANCY WALLS / FLOORS

In a traditional standalone kiwi home, the internal walls have typically been constructed with single stud timber frame with Gib or equivalent wall boards either side. This construction is very simple, and lightweight but does not reduce sound by very much, and is often described as ‘paper thin’ – typical STC around 30. Floors similarly have been fairly simple in nature

There are currently no building code requirements for sound insulation of internal walls, ceilings or floors within a residence. Many older standalone kiwi homes are single level and this combined with typical room arrangements in houses has often been used to reduce noise e.g. halls separating bedrooms from living spaces. In Europe building codes will sometimes specify minimum requirements for internal walls though these are much lower than for IT walls.

However within a household, doors will often be open, hearing one another in many cases be beneficial – e.g. for child care - and people within the household have more control of noises happening within the space. Even with high specification internal walls there is usually a common ceiling or floor space through which sound can also carry, and doors will limit the actual sound reductions possible in practice

However in housing units where better sound insulation within the dwelling is desired for better acoustic comfort (for example for privacy in bathrooms or between bedrooms, or where bedrooms adjoin noisy living areas) principles for sound insulation for IT walls/floors can just as easily be applied, if not to the same standard.

D2.2.4 SPACE PLANNING

The sound insulation requirements can be minimised and common problems avoided by adequate consideration of space planning. Sources of noise should not be located too close to quiet rooms within medium density housing. For example, rooms like bedrooms and living rooms should be located away from noise sources such as lift cores, driveways and garages without compromising passive solar design principals. Avoid putting laundries, bathrooms or living rooms next to, above or below bedrooms without adequate sound insulation and consider mounting noisy appliances on sound absorbing pads.

Avoid locating plumbing and waste pipes close to quiet rooms or ensure that they are adequately treated. Arranging bathrooms and kitchens in different apartments above each other reduces pipework and concentrates services. Provide extra sound insulation for noisy rooms such as laundries and use built-in robes as sound buffers between bedrooms. Use solid core doors instead of hollow core doors as they are more effective in sound insulation. Use acoustic or draught seals to gaps and doors to reduce sound transmission.

D2.3 INTER-TENANCY IMPACT NOISE

For housing, impact noise is especially noticeable for floor/ceiling elements through things like footsteps, chairs scrapping, and items dropped on the floor.

However, impact type noise can also be generated though things like cupboard doors and drawers banging against walls, hammering, and vibrations from machines and building services (eg vibrating washing machine, pipes, ventilation systems). Building services noise from vibration is generally handled by isolating the generating item from the building structure to reduce transmission, and will be considered separately in section D2.5.

This section focuses on the measurement and performance criteria for inter-tenancy (IT) impact noise.

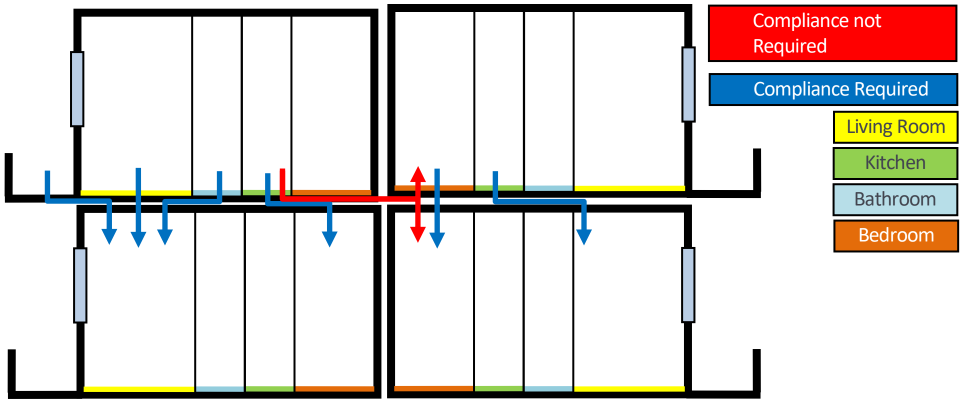
D2.3.1 INTRODUCTION AND CURRENT BUILDING CODE REQUIREMENTS

At present the NZ building code covers impact noise from an upstairs occupancy to habitable spaces below. The construction details for IT floors need to exceed the minimum NZ Building Code requirement as outlined in section D2.1, namely that

- noise transfer from any part of a household unit to a habitable space of another household unit is controlled to achieve the following performance requirements for shared building elements: Impact sound insulation performance for floors of not less than IIC 55 / FIIC 50.

As noted in D2.1, determinations on the building code confirm that for the current code as worded, that diagonal transmission to another household unit across inter-tenancy junctions, and flanking paths to neighbouring rooms do not require compliance, see figure 3.1.5a

Figure 13: Example of Impact Sound Transmission Paths and current NZ Building Code compliance requirements. Source: Marshall Day Acoustics



Product and system manufacturers do not normally provide IIC and/or $L_{n,w}$ ratings for complete IT floor/ceiling build-ups. For this reason determining the impact floor system with current building methodologies typically requires expert consultation.

Typical scenarios, for a concrete and timber structure are outlined below to illustrate this issue:

Concrete

The impact performance of concrete floor slabs can be tested in the laboratory. They can be tested with a ceiling arrangement but ceiling arrangements vary considerably and the performance is likely to differ with different suspension systems, plasterboard cavity size etc. The impact performance of a concrete system is heavily dependent on the floor finish. For hard floor areas an acoustic underlay is required below the hard floor to enable compliance with IIC 55. The floor finish and underlay can be tested separately (ΔL dB) and then the result 'added' to the performance of the floor/ceiling system (in each 1/3 octave band). These calculations are not difficult but in general the knowledge is not accessible to non-expert designers.

Timber floor systems

The rating of timber structure floor/ceiling systems are typically provided for either a bare floor or for a system with carpet. Calculation of overall impact performance of a timber floor system is much more challenging acoustically than concrete floor. The testing of floor finishes and acoustic underlays are all undertaken on concrete test slabs and the results do not directly relate to the performance on a timber structure.

When in place the performance is reduced due to transmission between elements and it is critical that junction design is carefully considered to reduce flanking paths. Flanking transmission of impacts along common floors can be a particular problem.

The IIC and $L_{n,w}$ descriptors operate for frequencies above 125Hz and 100Hz respectively, so tell you more about the performance for scraping and tapping type noises than the low frequencies of heavy footsteps. For these lower frequencies construction materials can have a large effect, with concrete tending to outperform light timber structures for this aspect.

D2.3.2 PROPOSED UPDATE TO CLAUSE G6

The current building code uses the ASTM impact Insulation Class IIC rating, with the Clause G6 compliance document referring to the field test equivalent (FIIC) being accepted at lower levels. The proposed codes aim to move to the ISO method of assessing impact noise which rather than being a sound reduction measure, measures the relative sound level on the other side of an element being impacted with a standardised 'tapper'.

Again the plan is for the building code to use a field metric, $L'_{nT,w}$. (Weighted, Standardised Impact Sound Pressure Level) so that all flanking paths are incorporated in the assessment of the impact insulation performance of the final building. The lower the $L'_{nT,w}$ result the better the performance of the floor. The aim is to improve the $L'_{nT,w}$ performance level required by several dB compared to the equivalent current FIIC criteria of 50.

The idea is to include performance requirements not only for noise from one household unit to another but also from common spaces (eg corridors) above a habitable space. For smaller areas with less traffic there may be an allowance for a slightly lower performance requirement. Testing will also be required in more spaces to check for unwanted flanking transmission, not just in the unit directly below the sound source.

Carpet and floor coverings can have a significant impact on IT impact performance and one point of note is that where the covering has been included as part of the impact performance measure, on its removal the floor alone may not meet the criteria. Raising awareness of this for those replacing floor coverings is an important consideration.

Currently, to meet impact and sound insulation requirements, most IT floors consist of an upper structural floor, with some kind of suspended ceiling with sound insulation material in between. However, where the floor is continuous under an IT wall there a chance of significant impact noise transmission to the next door room if careful consideration of junctions isn't made. One method to address this is the use of floating floors, where a floor surface is separated from the structural floor by an isolating layer, within a household unit. Floating floors are widely used in Europe but are only beginning to make an appearance in Nz – see section 6.3.3 for more

D2.4 EXTERNAL NOISE

D2.4.1 INTRODUCTION

Limiting the intrusion of external noise is an important consideration in creating a quality acoustic environment.

In typical suburban areas within New Zealand, controls relating to external sound insulation are not generally required. It is only when dwellings are to be located in potentially high noise areas that sound insulation controls are considered.

Controlling the intrusion of noise into dwellings fulfils two key roles: firstly the control of external noise provided a minimum standard of acoustic quality for the occupants; secondly, controlling external noise intrusion reduces the risk that new occupants will be adversely affected, thus reducing the potential for such occupants to attempt to control existing noise generating activities in the area. It is often the second function known as "reverse sensitivity" that is the primary driver for the current external noise control requirements in New Zealand.

D2.4.2 CURRENT MANDATORY REQUIREMENTS

The degree of external sound insulation required is determined primarily by the location of the dwelling and its proximity to noise generating activities, rather than any specific features of the dwelling itself. Because the requirements are location specific they have been developed and enforced through District Plans and Resource Consent conditions rather than in the Building Code.

Enforcement of sound insulation performance through the standard building inspection process can be problematic as the consent process is designed to achieve compliance with the limited provisions of the Building Code and not additional requirements contained for example, in the relevant district plan.

D2.4.3 DISTRICT PLAN LIMITS

The control of external noise requires consideration of three factors:

1. external levels incident on the building
2. appropriate internal noise level
3. performance of the building envelope

If the external noise levels and the internal design criteria are known, then the required performance of the building envelope can be calculated. Difficulties can be experienced in accurately quantifying external sound levels. For example, when future activities are being considered, or as is the case with an inner city environment, the external levels are highly variable. To undertake sound insulation calculations requires the external sound to be quantified in terms of overall level (dBA) as well as spectrum. The sound insulation requirements can vary considerably depending on the assumptions made.

However, external noise levels can be determined to a reasonable degree of accuracy by measurement of the ambient noise level over a representative period and by combining these with the noise level permitted by the district plan noise limits for the area under consideration.

Alternatively, the sound insulation performance of the façade can be specified directly without direct reference to the internal levels or external levels.

There is not a consistent manner in which external noise intrusion has been considered within NZ. There are a variety of different parameters that have been used to quantify the internal noise environment i.e. dB L_{Aeq}, dB L_{A10} , dB L_{dn}, NCB and L_{max}. The performance of the façade has also been specified as either a simple level difference in dB and as a more specific performance requirement dB $D_{tr,2m,\ nTw}$.

District Plan examples

As an example of a level based control, the **Auckland Unitary** Plan rule E25.6.10 requires that "noise sensitive spaces" in business zones must be designed and/or insulated so that the internal noise levels at night do not exceed" 35dB L_{Aeq} 45dB at 63 Hz L_{eq}; and 40dB at 125 Hz L_{eq} "based on the maximum level of noise permitted by the zone or precinct standards or any adjacent zone or precinct standards". This approach enables the sound insulation to be tailored to the specific situation but assumptions related to the spectrum of the sound source need to be made and this can create inconsistencies in assessments. The PAUP does not include consideration of traffic, or other unregulated noise sources. Previous versions of the Auckland area plans included references to specified 'high noise routes' and required sound insulation of residences near such roads. For example the City of Auckland District Plan Ishmus section 7.8.2.11 Acoustic Privacy required similar internal levels (i.e. 35 dBA night-time) to be met when properties bordered a "Strategic, Arterial or Collector Road."

The **Wellington and Christchurch District Plans** rules for dwellings in the central city, both use a façade performance specification rather than specified internal and external levels. For example, for dwellings within the Courtney Place Area of the Wellington District Plan Central Area, rule 13.6.1.2.1 states: *"any habitable room in a building used by a noise sensitive activity … shall be protected from noise arising from outside the building by ensuring the external sound insulation level achieves…* $D_{nT,w} + C_{tr} > 35$ *dB"*. This approach is potentially less tailored to specific situations but effectively covers all potential sources and also provides a greater degree of consistency in the level of sound insulation provided. However, it fails to conform with the resource management principle of the control of effects in that it may result in over expenditure on sound insulation in quiet areas and under insulation in noisy areas.

It is noted that the $D_{nT,w} + C_{tr}$ measure is designed for room to room measurement. The more applicable measure for facade treatment is the dB $D_{tr,2m,\ nTw}$ as used in the Christchurch Operative District Plan for residential developments in the Central City zone. Measurement of compliance with a façade noise standard does require measurement of noise outside the façade and in some instance can also require using loudspeakers suspended in front of the façade to generate adequate noise levels onto the façade. This can be difficult logistically in a tall building. The compliance issue can be partiality addressed by independent certification of the building acoustic design

In addition to noise from general industry, sound insulation requirements are provided by key noise generators including road and rail, ports and airports. Area specific requirements are incorporated into District Plans.

D2.4.4 OTHER KEY GUIDELINES

WHO Guidelines—

The WHO Guidelines for Community Noise were revised in 1999/2000 **[2]**. This document provides guideline values for the onset of health effects from noise exposure. The 1995 version recommended guideline values for sleep protection of 30 - 35 dB L_{Aeq} and 45 dB L_{Amax} in bedrooms at night. In the revised 2000 version this was adjusted slightly to be 30 dB L_{Aeq} and 45 dB L_{Amax}. The WHO document converts this to outdoor levels of 45 dB L_{Aeq} and 60 dB L_{Amax} at night based on a partly open window noise reduction of 15 dB.

A new day time criterion was added in the 2000 WHO Guidelines for controlling annoyance which is an outdoor exposure of 50-55 dB $L_{Aeq,(16\ hour)}$. Applying the same outside to inside noise reduction of 15 dB and the approximate conversion of $L_{dn} = L_{Aeq,\ (16\ hour)}$ this criterion is equivalent to 35 – 40 dB L_{dn} indoors.

In 2009 WHO published the Night Noise Guidelines for Europe which introduced a new metric L_{night} which is the outdoor 12 month average

8 hour L_{Aeq} (11pm – 7am). The recommended guideline value for no adverse effects is 40 dB L_{night} outdoors however an achievable interim target of 55 dB L_{night} is recommended. This is based on an average outside to inside noise reduction of 21 decibels[1] which means the 55 dB interim target is equivalent to 34 dB L_{night} indoors.

AS/NZS 2107:2016

Australian/New Zealand Standard "AS/NZS 2107:2016 Acoustics—Recommended design sound levels and reverberation times for building interiors" [11] provides the guidelines for internal noise levels within dwellings:

The standard includes a design sound level ($L_{Aeq,t}$) range for houses and apartments in various settings and times. For example, for an apartment in a suburban area or near minor roads it suggests aiming for $L_{Aeq,t}$ in the range 30 to 40 for living areas, 35-40 in work areas, and 30 to 35 in sleeping areas at night. For rural dwellings away from roads the range for sleeping areas at night is a little less 25-30, while in inner city areas a little higher 35-40.

These guidelines are used as a reference for specification of internal level criteria.

The standard notes that it is not intended for "either the assessment or prescription of acceptable recommended noise levels from transient or variable noises outside the building such as—

(i) aircraft noise (see AS 2021 or NZS 6805);

(ii) construction noise such as jackhammers and pile-drivers (see AS 2436 or NZS 6803);

(iii) railway noise; NOTE: AS 2377 gives methods of measurement for railway noise.

(iv) road traffic noise (see AS 3671 or NZ 6806);

(v) crowd noise, e.g. from parades and sporting events;

(vi) emergency vehicle audible warning devices; and

(vii) industrial and commercial noise."

NZTA Guidelines

The New Zealand Transport Agency (NZTA) provide reverse sensitivity guidelines that aim to control the effects on dwellings near state highways.

https://www.nzta.govt.nz/assets/resources/effects-on-noise-sensitive-land/effects-on-noise-sensitive-land-use.pdf

The NZTA's Highways information portal provides further guidance as well as technical information and software tools to assist with the – control of traffic noise .

https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/noise-and-vibration/

[1] This accounts for people having windows slightly ajar at night for half of the year

G6.3.4 Noise from sources external to the *building*

The sound received in a *habitable space* of a *household unit* due to *noise* external to the *building* must meet the performance requirements in Table 4.

Limits on application: Applies to *household units* located in *noise* zones identified in district plans prepared under the Resource Management Act 1991.

> **Comment – External noise**
>
> 6.3.4 applies to all *household units* (ie, standalone houses, attached units and units in apartment buildings) located in *noise* zones specified in District Plans. Examples of *noise* zones are *noise* contours around airports, and maximum *noise* limits for land use zones.
>
> Reference to District Plans helps ensure the degree of protection is relevant to the local external *noise* level and integrates the *Building Code* with the RMA.

Table 4: Noise from sources external to the building performance requirements

	Receiving space	Source	Performance requirement
(i)	*Habitable spaces* of *household units*	*Day-time external noise* level specified in the District Plan	$L_{Aeq} \leq 45dB(A)$
(ii)	*Habitable spaces* of *household units*	*Night-time external noise* level specified in the District Plan	$L_{Aeq} \leq 35dB(A)$

Comment
The requirements for protection against environmental *noise* are triggered when buildings are located in *noise* zones specified in District Plans established under the RMA. Examples of noise zones in District Plans include rural and residential zones, and airport noise control boundaries.

D2.4.5 PROPOSED BUILDING CODE

The earlier 2010 Proposed Clause G6 consultation document [24] contained the proposed criteria G6.3.4 as shown to left

It was intended that the external source incident on the building envelope would include

- the allowable zone noise limits for permanent sources specified in the district plan
- noise defined in a control boundary or noise contour in the district plan maps around an aerodrome, helicopter landing area, port, quarry or other site;
- noise from road and railway designations in the district plan.

Therefore the proposed building code would condense the various sound insulation requirements into a single criterion. Assessment of compliance would be part of a more typical Building Consent pathway. The Building Code would take over from the District Plan requirements making current District Plan sound insulation requirements invalid [*2018 addendum – this legal aspect needs to be clarified]*

D2.5 BUILDING SERVICES NOISE

D2.5.1 INTRODUCTION

It is common for dwellings in New Zealand to be without centralised ventilation, heating or cooling. In traditional houses and single level attached units the services are accommodated within the unit and noise control treatment is not commonplace.

Due to the lack of mechanical ventilation systems in New Zealand apartments the primary source of noise nuisance from building services in existing units and apartments is plumbing. Rigid connections can transfer noise from waste and supply pipes through common floors and walls.

There has been a significant adoption of heat pumps (BRANZ Study Report SR 329 [64]) in recent years and it is expected that mechanical ventilation and air conditioning will become more common. This is especially true in apartment developments located in busy urban areas where mechanical ventilation and cooling systems are needed in conjunction with external façade acoustic requirements.

Appropriate treatment of building services is an important part of providing a quality acoustic environment and appropriate noise control techniques will become more important as the density of housing increases and mechanical services plant becomes more common.

In assessing performance criteria some consideration needs to be given to the relationship of the source and the receiving occupant. Most general mechanical services noise criteria have been developed with the intent of providing guidance to a designer of equipment to ensure such equipment provides a suitable quality of internal environment. More stringent criteria may be appropriate if the source is not associated with the occupant. For example, a criterion may be appropriate for ventilation system installed in an apartment but that same criterion would not be appropriate for the noise received by the neighbour's system. Similarly many popular high-wall systems have high speed settings that would not comply with typical 'quality' criteria. People are often willing to accept high noise levels from appliances that they control.

D2.5.2 CURRENT MANDATORY REQUIREMENTS

Building services equipment must comply with the standard District Plan noise limits at the adjacent property. It is uncommon for controls to cover noise transmission between dwellings within a single property. Some plans, such as Auckland PAUP rule E25.6.9 cover noise transferred through a common partition, but this does not cover centralised plant or the noise from outdoor equipment received and transmitted within the same property, for example outdoor condenser units on a balcony.

It is common for external sound insulation performance criteria to include a reference to the noise from mechanical services systems. This is done to ensure that the noise from the mechanical ventilation system does not result in higher levels than the mitigated external noise. An example of this is the Auckland PAUP ruleE25.6.10.3 (f) which requires external sound insulation treatment also "have a mechanical ventilation and/or a cooling system that generates a noise level no greater than L_{Aeq} 35 dB when measured 1m from the diffuser at the minimum air flows required to achieve the design temperatures and air flows…"

There are no current requirements relating to plumbing noise control.

D2.5.3 OTHER KEY GUIDELINES

WHO and NZS 2107

The WHO Guidelines [2] and AS/NZS 2107:2016 [11] summarised in section D2.4 are also applicable to constant building services noise sources such as ventilation and air conditioning systems.

AAAC Guide

The Association of Australasian Acoustical Consultants (AAAC) publishes a guide for building services noise in their Guideline for

Apartment and Townhouse Acoustic Rating [31] . (this is available for download at http://www.aaac.org.au/resources/Documents/Public/Apartment%20and%20Townhouse%20Acoustic%20Rating%20V1.0.pdf, see table 2 of section 9 for Internal Building Services). The criteria are intended to provide an indication of acoustic quality and apply to general HVAC sources both controlled externally and under the control of the occupant but not to “appliances such as spa baths and dishwashers”. A penalty of up to 5 dB is applied to tonal or impulsive sources.

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers

The 2015 ASHRAE Handbook – Table 1 of Chapter 48 Noise and Vibration Control contains NC/RC and overall sound pressure levels design guidelines for HVAC systems in residences.

Table 3: Building services and building movement noise performance requirements

	Receiving space	Source	Performance requirement	Comment
(i)	*Habitable space* in a *household unit*	*Building services* serving spaces other than the household unit containing the receiving space	$L_{Aeq,10s} \leq$ 22dB	$L_{Aeq,10s}$ measures the A-weighted sound pressure level over a 10-second period. *Building services* such as water pipes, drains, ventilation and lifts can cause *noise* annoyance. It is possible to reduce these *noise* sources so they are virtually inaudible at reasonable cost using methods such as lagging and isolating mounts. The value $L_{Aeq,10s}$ 22dB has been chosen because it is virtually inaudible and is the lowest level to which Type 1 sound level meters can measure.
(ii)	*Habitable space* in a *household unit*	Equipment installed to provide HVAC services to spaces other than the household unit containing the receiving space	NC ≤ 25	Where HVAC equipment is installed in a building containing household units or unit, a maximum noise performance level is set. The Noise Criteria (NC) measure is that commonly used by the HVAC industry to rate the noise performance of such plant or systems.

D2.5.4 PROPOSED BUILDING CODE

The 2010 proposed G6 consultation document [24] contained this table of criteria (left) in relation to Building Services noise.

Two separate criteria are outlined in this document. There is a criterion for intermittent sources such as plumbing and a separate criterion for more consistent HVAC sources. Each criterion has a specific measure appropriate to the type of source being assessed.

It is understood that the most recent proposals for the Clause G6 update include a single criterion of $L_{Aeq\ (30s)}$ 30 dB.. This criteria is similar to the previously propose HVAC criterion of NC 25 but for intermittent sources the criterion is much less stringent (by approximately 10 dB).

The criteria only apply to sources generated outside the household unit.

D2.5.5 AUSTRALIAN BUILDING CODE

The Australian Building Code controls building services noise not by specification of the noise levels but by specification of the partition separating the services from the occupancy.

F5.6 Sound insulation rating of internal services

(a) *If a duct, soil, waste or water supply pipe, including a duct or pipe that is located in a wall or floor cavity, serves or passes through more than one sole-occupancy unit, the duct or pipe must be separated from the rooms of any sole-occupancy unit by construction with an* R_{w+Ctr} *(airborne) not less than—*

(i) 40 if the adjacent room is a habitable room (other than a kitchen); or

(ii) 25 if the adjacent room is a kitchen or non- habitable room.

(b) If a storm water pipe passes through a sole-occupancy unit it must be separated in accordance with (a)(i) and (ii).

F5.7 Sound isolation of pumps

A flexible coupling must be used at the point of connection between the service pipes in a building and any circulating or other pump.

D2.6 BUILDING SITING

One of the key drivers for the development of medium density housing is the desire to intensify around transport corridors and commercial hubs. From a sustainability and city planning perspective, this has advantages for getting people to use public transport more, and having more people closer to centralised amenities. However, from an acoustic perspective traffic corridors and busy town centres are noisy and the outdoor sound levels are much higher than in the suburbs.

The siting of housing in these locations is to some degree inevitable but is not ideal acoustically. When ambient noise levels are high (e.g. in the inner city, by an airport or port) you can expect, a higher percentage of people to be annoyed. Good sound insulation and appropriate window design and ventilation systems in the building envelope can be used to reduce the noise levels to acceptable levels inside the housing unit except near the very noisiest sources, but it will not generally be easy to achieve the same acoustic quality for external living spaces or when windows are open. Natural ventilation is desirable for other reasons. (see sections D3.1– ventilation).

This trade off is one of the key points in relation to quality MDH acoustic design. Ultimately the building code sets out basic acoustic performance criteria the building must meet (at present only for the internal spaces of the housing unit) but Councils must decide where those buildings can be built. The assessment of noise effects on the residents should be included at the building planning and approval stage

It may be appropriate for controls to be provided for outdoors living areas as well as internal spaces. In any case the noise amenity provided by most buildings could be improved by considering the arrangement of the building in relation to eternal sources in the following ways:

D2.6.1 SITE PLANNING

It is important to consider noise sources when locating a building on the site and when positioning the windows on the building facade.

Noise levels can vary at different times of the day and sources can come from a variety of causes such as; road noise, commercial shops or tenancies, industrial premises, hotels, entertainment venues and garbage and recycling.

Intermediary buildings can also provide a buffer from busy roads for example. The position on site and even building shape relative to noise sources can impact, e.g. to ensure noise isn't reflected into quiet areas.

D2.6.2 CONSIDERATION OF PLANNING FOR ADJACENT NEIGHBOURS

Sources of noise within the site such as noise from outdoor living areas, communal areas and swimming pools should be located away from neighbour's windows. Noisy air conditioners and service pumps should be placed far enough away and well shielded from tenants and neighbours by a wall or vegetation. Noise from these can be reduced through the use of noise reduction enclosures.

It is important to consider the use of hard exterior landscaping surfaces such as concrete and concrete paving as these reflect sound rather than absorb it. Softer landscaping surfaces are more desirable for medium density housing.

D2.6.3 SCREEN WALLS, FENCES AND VEGETATION TO MITIGATE NOISE

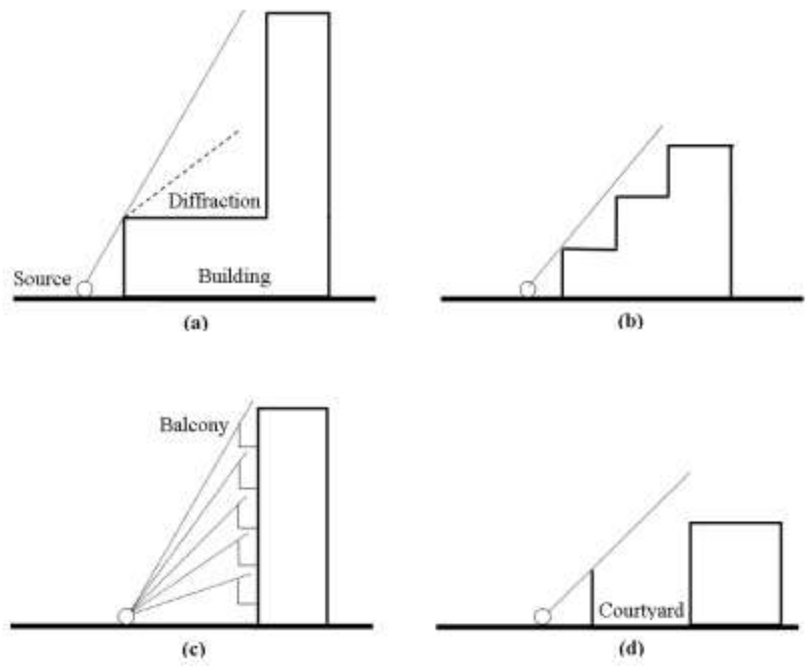
Installing purpose designed fencing or a sound wall can provide noise abatement and shield housing from noise sources. These solutions can be large, tall and unattractive but they can be successful when housing is located next to more public areas or areas with a non-domestic use.

Screen walls can be used to shield outdoor living spaces from vehicle noise. Acoustic material can be used to absorb external airborne sound and reduce reflection. Vegetation, although not particularly effective at reducing noise transmission plays an important role in making noise barriers more palatable.

D2.6.4 BUILDING DESIGN AND DETAILING

The design of the building themselves can be used to provide effective screening. Outdoor living areas and façades with more sensitive rooms can be protected by less sensitive areas.

Different Building Designs to Deal with Noise Source



D2.7 RAIN NOISE

Noise is generated with the impact of rain on a roof. The noise level varies with intensity of the rain as well as the construction of the roof. People's reaction to rain noise also varies. Some people enjoy the sound of the rain on the roof while others do not.

A typical residential New Zealand roof construction consists of profiled metal roof, building paper, fibrous insulation blanket and a plasterboard ceiling. With this construction, during the very heaviest rain fall (40 mm/hr) the noise levels from rain will be up to 50 – 55 dB inside. Moderate to heavy rain is clearly audible above other typical background sources but is not often sufficient to cause significant sleep disturbance.

It is not common for builders of standard houses and apartments to include additional rain noise control. It can be assumed that this level of protection is considered acceptable and an appropriate quality benchmark. It is not anticipated that significant additional treatment to standard construction will be investigated in detail as part of the project.

However, there are several new technologies that are becoming common in the commercial building and these may change how rain noise is dealt with. As an example, composite foam and steel sandwich style roofing systems create levels of rain noise similar to bare steel. This type of construction is becoming more common in commercial applications. If these type of systems were used without fibrous insulation or plasterboard ceiling the rain noise would be significantly louder than what is currently experienced with the standard New Zealand roof.

The project will seek to identify trends that may result in higher rain noise levels and determine whether the significance of these trends requires further research or more formal guidelines.

D2.8 DETAILING AND WORKMANSHIP

Even when acoustic recommendations are incorporated into the overall building design, the on-site acoustic performance of the finished building relies on the building contractors' attention to detail and workmanship. The following describes certain key areas for attention. However this is not a comprehensive list.

- The building contractor must insure all building elements are installed to meet the acoustic requirements of the product/system used.
- The contractor needs to ensure that the method of installation of acoustic treatment follows all manufacturers published statements and does not allow for site influenced deficiencies to arise that compromise acoustic performance.
- All penetrations in ceilings and external building elements must be sealed with approved acoustic sealant. Sealants used for acoustic purposes must be polyurethane or silicone based Class A sealants, with a joint movement capability of ±25% of the original joint width. The use of Class B acrylic sealants, which only have a joint movement capability of ±10% of the original joint width, is not acceptable because of problems with long term cracking and poor adhesion, caused by hardening of the seal over time.
- Door and window seals must be fitted carefully to ensure the seal engages around the entire perimeter when the door or window is latched shut. Doors must close and latch easily without leaf bowing.

The Australian Building Code Board "Sound Transmission and Insulation in Buildings 2016 Handbook" [60], provides an excellent summary in Chapter 5 of good practice tips for construction which should be applied during the building phase, which are equally pertinent in NZ.. Volume 1 Chapter 10 of Cost Action Tu0901 [12] also collates many typical workmanship errors.

D2.9 EXPERT ADVICE

It is common for acoustic consultants to be engaged to provide expert advice during a largescale residential development project, but is not compulsory. The involvement of an acoustic expert on the project provides greater certainty that the acoustic objectives would be achieved. For large projects the cost of an expert acoustic review is relatively small (often 0.1 % of construction costs) and this cost is soon regained by efficacies in the building design and by reduced risk of substandard construction. However expert advice on small to medium projects can be less cost effective and more difficult to manage. Ensuring there is sufficient knowledge available to industry to provide good noise control with standard constructions is therefore important.

The services that could be provided by the consultant on a typical apartment project can include:

Design Stage

- Determine acoustic design criteria in line with Building Code requirements and client expectations. Criteria would cover airborne and impact sound insulation for the apartments, as well as other considerations such as mechanical services. An initial site visit and ambient noise survey would be undertaken.
- Attend design concept meetings to ensure critical acoustic considerations are incorporated from the earliest stage in the project.
- Review developed architectural drawings and proposed surface finishes
- Identify areas of acoustic concern and address issues through Design Advice Notes to the architect
- Review detailed architectural drawings to ensure that acoustic requirements are incorporated
- Prepare acoustic design report summarising the acoustic requirements and assessing the construction design against the Part G6 of the Building Code. This report would be suitable for submittal as part of a Building Consent
- If required a Producer Statement PS1 would accompany the acoustic design report

Construction Stage

- During construction, the consultant is generally available to carry out site inspections to check progress and offer advice on detailing as required.
- Upon completion of construction, they would also be available to measure the performance of inter-tenancy walls and floors, and external noise reduction to ensure compliance with agreed standards and consent requirements and produce PS4 if required

PS1 and PS4 are types of Producer Statement, part of the compliance options for the NZ Building Code.

D3 RELATED FACTORS

Design experience from the research team has identified the following related factors that can most notably influence acoustic design and impact internal acoustic quality.

- Structural Design
- Fire Performance
- Thermal comfort and ventilation requirements
- Lighting / Glazing
- Water tightness
- Sustainability
- Building Trends / Aesthetics
- Economic

The following sections provide overviews of the types of conflicts that occur between acoustic requirements and each of these related factors. In some cases the factors can also be complimentary. For example, using insulation products that provide acoustic and thermal insulation, as well as meeting fire compliance requirements.

D3.1 STRUCTURAL DESIGN ASPECTS THAT INFLUENCE ACOUSTICS

The structural design of MDH can have a significant influence on acoustic performance.

Key aspects of the structure design that influence acoustic performance can be broadly categorized as:

- structural connectivity
- structural materials and systems
- dynamic response of structural elements

In this section, each of these aspects is considered for the main structural systems applied in typical MDH. In addition, the design requirements under clause B1-Structure of New Zealand Building Code that may affect acoustic performance are highlighted.

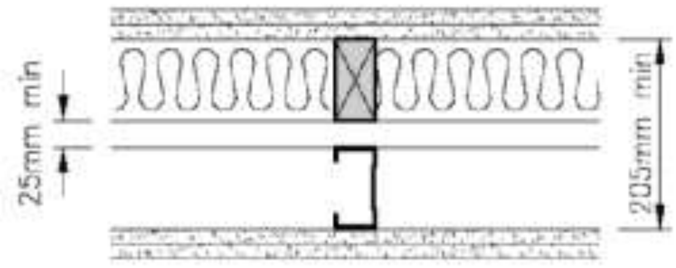
D3.1.1 INTERTENANCY WALLS

The structural systems/materials that are commonly used for IT walls are precast or in-situ-poured reinforced concrete, reinforced masonry block and light timber/steel framing. Notably, solid timber IT walls systems constructed from cross-laminated timber (CLT) and Triboard have gained in popularity. Some common examples of IT walls are given in Table 3. Refer to the 2010 Clause G6 Public consultation document [24] for further information and common examples of standard code-compliant IT wall systems.

Due to the low density/mass of light timber/steel frame walls (relative to concrete and masonry walls), there is limited acoustic attenuation through a single wall. Usually adequate acoustic performance is achieved by using a double light timber/steel frame arrangement. To limit flanking transmissions across tenancies it is preferable (from an acoustic perspective) to completely isolate one frame from the other. An alternative option is a single timber frame wall but to incorporate an acoustic clip/ isolator.

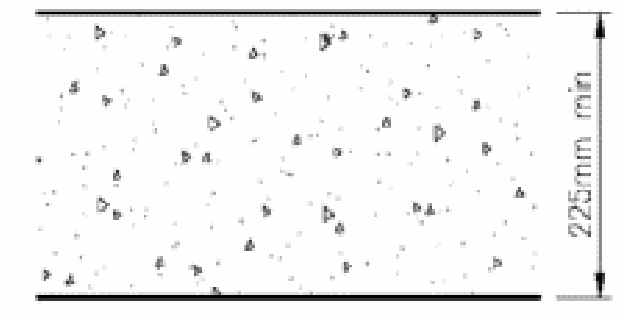
Table 3: Common IT walls: a) Light timber/steel frame, b) Cast-insitu concrete, c) Precast concrete, and d) Masonry block. Source - Table 5 of 2010 proposed G6 [24]

a)



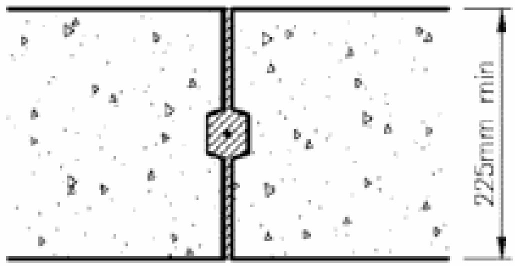
- 2 layers 13mm plasterboard lining with staggered joints, 8.5kg/ m^2 /sheet minimum each side of double steel or timber studs on separate plates (Note 2)
- Sound absorbing materials in cavity (Note 1).
- Framing may be timber or steel

b)



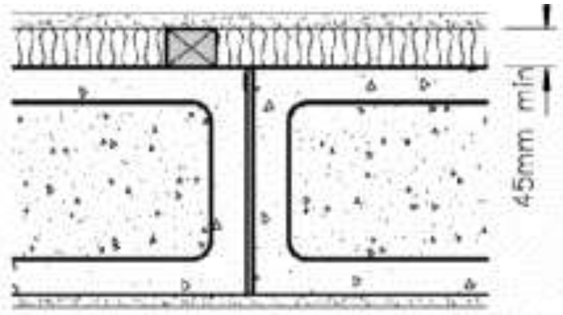
- Solid concrete wall not less than 225mm thick. Density 2300kg/m^3 (minimum). Surface finishes shall be paint, or hard plaster, wallpaper or adhesive direct fixed plasterboard (Note 2).

c)



- Precast concrete wall panels not less than 225mm thick. Density 2300 kg/m^3 (minimum). Surface finishes shall be paint, hard plaster, wallpaper or adhesive direct fix plasterboard (Note 2)
- Joint filled with concrete grout

d)



- 20 Series solid fill masonry blocks. Minimum surface density 375kg/m^2.
- 1x10mm plasterboard (6.5kg/m^2 minimum) on 45mm (minimum) timber or steel battens at 600mm centres (Note2)
- Sound absorbing material in cavity 50mm thick (Note 1)
- 1x10mm plasterboard adhesive fixed directly onto blockwork, or 10mm hard plaster.

Note1 – Sound absorbing material: Fibrous sound absorbing material with flow resistivity not less than 200 rayls (mks) and not more than 1000 rayls (mks) 75mm thick minimum.
Note 2 – All perimeter junctions between walls and floors must be sealed airtight.

For structural, architectural, acoustic, fire and economic reasons certain structural IT wall systems/materials may be favourable over others for a given MDH project. Generally the structural requirements behind the selection of a given structural system/material for an IT wall are related to the vertical load capacity of the system, the lateral load capacity of the system (to resist wind, seismic and post-fire stability loads) and its weight. More specific structural design requirements that may influence acoustic performance are summarised below:

D3.1.1.1 Structural system/materials selection:

Walls with high vertical load capacity may be required to support heavy floor or roof systems. Similarly, wall system with high lateral load capacity may be required to resist high seismic or wind loads. An example is terraced units where there is a lack of structural bracing across the unit (usually on the lower floor) and the IT wall is designed to provide bracing in its weak direction (across the unit) for wind, seismic and/or post-fire stability loading. These situations may favour reinforced concrete or masonry block IT wall rather than light timber/steel framing, which inherently influences acoustic performance.

A corollary argument is that materials may be selected for the IT walls which minimise building weight and therefore gravity and seismic demands on the structure, such as light timber/steel framing. For light timber frame IT walls there are two main types of structural arrangement; platform or balloon type framing. For platform framing the floor framing extends over and sits on top of the IT wall (most common). For balloon framing, the floor is supported by corbels or blocking off the face of the IT wall. The selected framing arrangement may affect acoustic performance. For example, platform framing may provide additional acoustic flanking pathways across IT wall lines/tenancies.

D3.1.1.2 Structural diaphragm continuity:

For terraced units and apartments, there may be a structural requirement to connect the floor diaphragm from one tenancy to the next through the IT wall. This situation arises is if structural bracing is provided outside a given tenancy or if differential lateral movement from one tenancy to the next is of concern.

For example, if each terraced unit is self-braced (i.e. does not require structural bracing from outside a given tenancy) and does not have sufficient diaphragm connection through IT walls, each tenancy could theoretically oscillate independent of one another under seismic or wind loading; resulting in pounding between tenancies or damage to exterior cladding. Depending on the chosen structural system and loadings, design lateral deformations may vary significantly resulting in larger or smaller gaps/joints between tenancies which may influence acoustic performance.

The effects of connecting the floor diaphragm across an IT wall junction can vary significantly depending on the IT wall system and the floor system. For reinforced concrete or masonry IT walls with concrete floors, the density/mass of the IT wall may be sufficient to provide adequate acoustic attenuation. However, for a double stud light timber/steel frame IT wall with light timber frame floors, connection of the floor diaphragm (usually comprised of plywood, strand board or similar panel products) can result in a significant acoustic flanking pathway.

For light timber/steel frame IT walls requiring structural connections, other measures are usually required to limit acoustic flanking transmission including the inclusion of a floating floor system (see section D3.1.2) or proprietary acoustic isolating connections (for example see images of Scion acoustic isolating connections in the BRANZ research paper [65]). Notably, a similar concept has been applied for solid timber IT walls using acoustic pads under the floor plates (for example see images in [66]). Key constraints for these elements are the structural performance/strength of the isolation connections or pads and their flexibility (not to mention cost). Under service level wind or seismic loads, significant deformation resulting in damage to structural or non-structural components (such as exterior cladding) is not acceptable (refer to section D3.1.4).

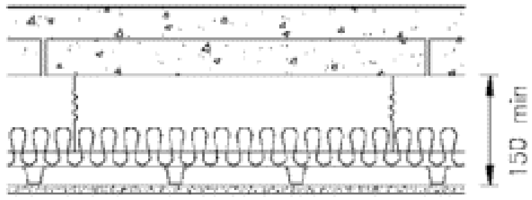
D3.1.2 INTERTENANCY FLOORS

The structural systems/materials that are commonly used for IT floors are precast or in-situ reinforced concrete, concrete/steel composite tray deck systems and light timber/steel framing. Light timber/steel frame floors systems incorporate structural floor sheathing such as plywood, strand board and cement board (or similar panel products). More recently, solid timber floors using CLT panels or prefabricated engineered timber hollow floor cassettes have been applied in some MDH projects. Some common examples of IT floors are given Table 4: Common IT floors: a) Precast concrete, b) Concrete/steel tray deck and c) Light timber framing with sheathing. Source - Table 2 of 2010 proposed G6 [24]. Refer to the 2010 Clause G6 Public consultation document [24] for further information and common examples of code-compliant IT floor systems.

Similar to IT walls, the low density/mass of light timber/steel frame or engineered timber panels/cassettes (relative to concrete and masonry) results in limited acoustic attenuation through a floor. In these situations, adequate acoustic performance is usually achieved by the addition of layers on top of the structural floor (such as an acoustic underlay, screed or floating floor system) and the suspension of layers below the structural floor (such as a suspended ceiling with acoustic insulation).

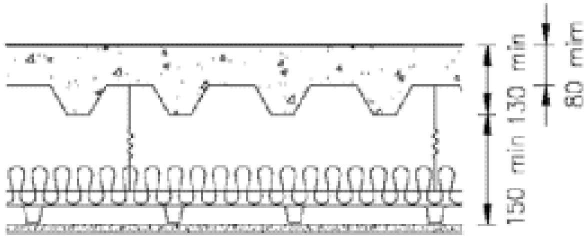
Table 4: Common IT floors: a) Precast concrete, b) Concrete/steel tray deck and c) Light timber framing with sheathing. Source - Table 2 of 2010 proposed G6 [24]

a) Precast slab and topping (min thickness 120mm, min avg thickness 120mm)



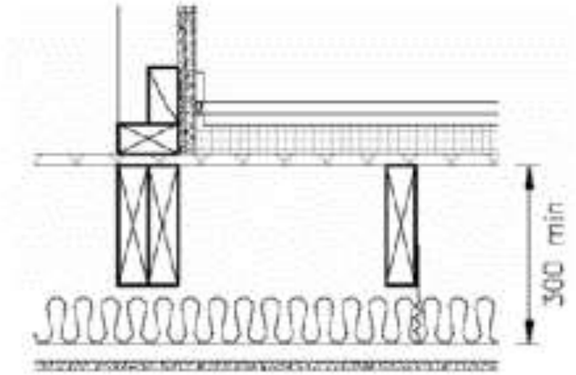
- Acoustically isolated ceiling system separated from any supporting steel beam by 25mm minimum
- 13mm, 8.5kg/m^2 min plasterboard ceiling lining
- Fibrous sound absorbing material with flow resistivity 200-1000 rayls, 75mm minimum thickness

b) Poured topping on trapezoidal profile permanent steel formwork (min thickness 80mm over ribs, 130mm in troughs)



- Acoustically isolated ceiling system separated from any supporting steel beam by 25mm minimum
- 13mm, 8.5kg/m^2 min plasterboard ceiling lining
- Fibrous sound absorbing material with flow resistivity 200-1000 rayls, 75mm minimum thickness
-

c) *Overlaid* on particleboard floor



- Any trafficable flooring on 20mm particleboard, 19mm plywood, 19mm strip flooring, 18mm compressed fibre cement sheet on
- Any product with Δ LnT,w 18dB minimum in cavity
- 20mm particleboard flooring on timber structural system
- 13mm, 8.5kg/m^2 min plasterboard ceiling lining on acoustically isolated ceiling system
- Fibrous sound absorbing material with flow resistivity 200-1000 rayls 75mm minimum thickness
- Resilient acoustic edge seal between trafficable flooring and vertical elements e.g.s wall linings, skirting boards.

The structural requirements for intertenancy (IT) floors in MDH generally include vertical support for gravity loads, providing an effective diaphragm for transferring lateral wind and in some cases fire stability. More specific structural design requirements that may influence acoustic performance are summarised below:

D3.1.2.1 Structural system/materials selection

Only some floor systems are capable of spanning longer distances. These floor systems may be required if there is basement car parking or a relatively open floor plan with few internal walls. Similarly, only some floor systems may be capable of transferring high/concentrated lateral loads when acting as a diaphragm. These floors may be required if seismic/wind loadings are high or if there is a sparse arrangement of lateral load resisting elements (walls or frames) supporting the floor. Another factor can be the deformability of the diaphragm; to limit lateral movement under wind and earthquake loading a stiff diaphragm (e.g. reinforced concrete) may be required.

Similarly to IT walls, floor systems/materials may be selected to minimise building weight and therefore gravity and seismic demands on the structure, such as light timber framing. In general, if the structural engineer is seeking to limit building weight, the possible acoustic treatments to the floor will be constrained. For example, the use of dry screes, sand or cement blocks on top of the light timber/steel floor system may not be achievable from a structural perspective. Also for light timber frame floors, the use of platform or balloon type framing may impact acoustic performance (as noted above for IT walls).

The material used for the structural sheathing on top of light timber/steel frame floors may also influence acoustic performance. While the structural engineer may select this material based on its ability to provide a structural diaphragm, some high density products such as cement board or magnesium oxide board may have better acoustic performance than say plywood, strand board or particle board.

D3.1.2.2 Structural diaphragm continuity

Refer to section D3.1.1 above.

D3.1.2.3 Occupancy-induced floor vibration

Floor vibration and acoustic performance can be interrelated. According to European Standard Eurocode 5 [67], there are two key criteria to check when assessing the vibratory performance of a timber floor; the natural frequency and the impulse acceleration. Both of these factors are influenced by the mass and stiffness of the floor which also influences acoustic transfer/attenuation. Therefore, the performance criteria applied by the structural engineer for floor vibration can indirectly influence acoustic performance.

Under the verification methods for the New Zealand Building Code (NZBC), there are no prescriptive requirements for floor vibration. The New Zealand Loadings Standard AS/NZS1170.0 [68] only provides the recommendation that the deflection of a floor under a 1kN point load shall not exceed 1 to 2mm. This is up to 4 times less stringent than European Standards (eg Eurocode 5 [67]). Therefore, the vibratory stiffness and mass requirements for floors in New Zealand may vary significantly from other countries. Again, these factors could significantly influence the acoustic performance of floor system – when compared to similar systems applied overseas.

Significant floor vibration may also activate noise sources from the IT floor system and/or any connected elements thus effecting acoustic performance.

D3.1.3 WINDBORNE VIBRATION

The structural design of roof and exterior wall systems for wind can effect acoustic performance. Similar to floor vibration, the New Zealand Loadings Standard [68] provides recommendations for deflection under service level wind loadings. However, the standard does not considered wind-induced dynamic response of structural elements that support wall or roof cladding.

For exterior walls and roofs constructed of light-weight materials with relatively low stiffness, dynamic response to wind loading is possible. Typically this occurs around building edges where wind eddies or vortices develop. This dynamic response to wind can activate noise sources from the exterior wall/roof or any connected elements.

D3.1.4 STRUCTURAL CODE REQUIREMENTS

There are general New Zealand Building Code requirements under Clause B1- Structure [23] which influence the acoustic performance of MDH developments. Under B1 there are general performance requirements such as avoiding structural failure and loss of amenity. These performance requirements are most commonly achieved through the verification method - VM1, which includes the loadings standard and the concrete, steel and timber standards.

Some key structural code requirements that influence acoustic performance are listed below:

D3.1.4.1 Structural diaphragm integrity:

Under the concrete and timber standard floors are required to act as structural diaphragms and transmit horizontal, as well as vertical forces. This requirement has a significant impact on the ability to acoustically decouple tenancies to avoid flanking paths as discussed in section D3.1.2.

D3.1.4.2 Floor deflection/vibration:

There are floor deflection and vibration recommendations in the loading standard which may influence acoustic performance by setting the mass or stiffness of a floor or potentially creating noise sources. See section D3.1.2 for further discussion.

D3.1.4.3 Lateral deformation:

Under the loadings standard there is the requirement to determine the lateral deflections of a structure under serviceability and ultimate limit state wind or seismic loading. As discussed in section D3.1.1, acoustically isolated IT walls may need to be adequately separated to allow for this deformation.

The cladding at IT wall junctions shall be adequately design to ensure Building Code Clause E2 - External Moisture [23] is satisfied when the structure is subject to serviceability-level deformations due to wind and seismic events (as defined in the loadings standard).

Furthermore, the recent 2010 draft amendments to the earthquake loadings standard NZS1170.5 [69] require that the predicted lateral deformations of a tenancy under ultimate limit state loadings must be increased by a minimum of 50%. This may result in increases to the gaps required between tenancies which in turn may influence acoustic performance.

D3.2 FIRE PERFORMANCE

In New Zealand, the design of buildings must meet fire protection Clauses C1-C6 of the NZ building code [70]. Clause C1 states that

"The objectives of clauses C2 to C6 are to: (a) safeguard people from an unacceptable risk of injury or illness caused by fire, (b) protect other property from damage caused by fire, and (c) facilitate firefighting and rescue operations".

As noted in the NZ Timber Design Guide [71] the immediate threat to life safety usually occurs in the early stages of a fire when occupants are likely to be trapped or overcome by smoke. Fire resistance is required at later stages in the fire to prevent fire spread or structural collapse which could threaten the occupants or property in adjacent areas. The severity of a fire and rate of fire spread are influenced by the design of the building.

Acoustic needs often contradict those of the structural and fire engineer. Just as a structural engineer often requires a well-connected structure for earthquake performance, fire engineers require continuity of fire rated systems to contain heat and smoke for as long as required in a fire. By contrast acoustic performance is generally enhanced by isolation of the structure between occupancies, so the key to optimum performance is careful consideration of the joint details between walls/floors/ceilings to balance acceptable performance across all three disciplines (for more see the 2013 BRANZ Study SR208 on optimized junctions [72])

In general fire compliance is strictly adhered to given its high safety consequences, and compliance in New Zealand can only be guaranteed via fire testing of each system in its entirety. This means there is less flexibility for non-tested/component-derived solutions in regards to fire compliance than for acoustic requirements.

Some specific examples of interaction between fire and acoustic performance are given below:

- Building elements between tenancies, or between tenancies and common spaces, in particular must meet higher fire ratings than within a residence to avoid spread outside the household unit.

  Because of this many commercial systems for intertenancy solutions will provide acoustic, fire and structural information together to show that systems meet all Building Code requirements. Also many materials are rated for both acoustic and fire performance (eg fire& acoustic rated plasterboard and insulation).

- Some aspects of fire design are complimentary with acoustic performance. Increased mass can result in better fire performance but are also beneficial acoustically. Denser products such as noise rated plasterboard which provide better acoustic performance often provide better insulation from heat which protects both the building element and the neighbouring property. To prevent the passage of noise and flames through building elements, airgaps, joints and penetrations (eg pipes, electrical sockets) must be sealed using fire rated foams or sealants, which help limit acoustic flanking pathways. Contrary to this, sealing air gaps that are intended to be acoustically isolated may reduce acoustic performance.

- Modern developments such as intumescent sealants which only expand when heated, will not provide the same degree of acoustic performance so, if used, separate acoustic insulation may also be required.

- When a design requires a certain fire rating for a door (eg 60 min) then care must be taken to choose doors with appropriate fire and acoustic ratings and seals

D3.3 TEMPERATURE CONTROL AND INDOOR AIR QUALITY

D3.3.1 INTRODUCTION

This section considers the temperature control, indoor air quality and environmental/sustainability issues associated with the acoustical design of medium density housing.

A defining characteristic of medium density housing and in particular apartments, terraced housing and duplex dwellings is that household units are attached to one another, occupants live in close proximity to each other to a varying extent and share common walls and roofs, floors and ceilings. As a result, two key conflicting environmental issues present themselves: keeping noise out and allowing air and light in.

Medium density housing is anticipated to become more prevalent in city centres, metropolitan centres, town centres and local centres which by their very nature will have higher background noise environments most often dominated by road traffic. The higher the traffic volumes nearby, the higher the background noise level.

Meeting acceptable noise levels particularly in bedrooms and to a lesser extent in other habitable spaces with openable windows for outdoor air supply and summertime temperature control is an associated acoustic issue for medium density housing in these types of location.

Specific issues addressed by this section include:

- Indoor air quality and temperature control issues in medium density housing located in environments subject to unreasonable noise and vibration particularly at night.
- Air quality issues associated with outdoor air ventilation in medium density housing with high levels of road traffic. In particular PM 10 and PM 2.5 particulates.

- The energy efficiency and sustainability of any associated temperature control and indoor air quality provisions.
- Climate Change Considerations
- Market Research – what people want
- Qualitative effects of HVAC equipment.
- Checklist of features to be considered in providing suitable indoor air quality and temperature control in medium density housing located in environments subject to high noise and vibration particularly at night.

D3.3.2 TEMPERATURE CONTROL, INDOOR AIR QUALITY REQUIREMENTS & ENERGY EFFICIENCY REQUIREMENTS

D3.3.2.1 Consent Requirements

Minimum requirements for temperature control, indoor air quality and related energy efficiency/sustainability are generally controlled by a combination of resource and building consents.

Resource Consents provide permission under the Resource Management Act to use land or national resources in a way that mitigates their effect on the environment. Permission is restricted by rules in operative district plans.

District plans seek to address these concerns such that:

- People are protected from unreasonable levels of noise and vibration
- The amenity values of residential zones are protected from unreasonable noise and vibration particularly at night.

Building Consents provide permission to construct buildings under the Building Act and the various Building Regulations which includes the Building Code. The Building Act seeks to improve control of and encourage better practices in building design and construction to provide greater assurance to consumers.

Building Consents seek to address these concerns such that:

- People can use buildings safely and without endangering their health.
- Buildings have attributes that contribute appropriately to the health, physical independence and well-being of the people who use them.
- Buildings are designed, constructed and able to be used in ways to promote sustainable development.

D3.3.2.2 District Plan Requirements

Consideration of temperature control, indoor air quality and any related energy efficiency/sustainability issues is generally limited at a district plan level to residential buildings that are located in urban environments that may result in high levels of noise and vibration to the extent that openable windows cannot be relied upon for outdoor ventilation and summertime temperature control.

Ventilation and Indoor Air Quality Requirements within District Plans appear to have evolved from consideration of residential activities which are sensitive to Aircraft Noise. Here is an example from the Rotorua District Plan 2016 (appendix A7.3 [73] in relation to airport noise in a noise control area).

The ventilation performance standard shall be:

Either:

(i) A mechanical ventilation system or mechanical ventilation systems capable of:

- *Providing at least 15 air changes of outdoor air per hour in the principal living room of each building and 5 air changes of* *outdoor air per hour in the other habitable rooms of each building, in each case with all external doors and windows of the building closed with the exception of such windows in non-habitable rooms that need to be ajar to provide air relief paths;*

- *Enabling the rate of airflow to be controlled across the range, from the maximum airflow capacity down to 0.5 air changes (plus or minus 0.1) of outdoor air per hour in all habitable rooms;*
- *Limiting internal air pressure to not more than 30 Pascals above ambient air pressure;*
- *Being individually switched on and off by the building occupants, in the case of each system; and*
- *Creating no more than 40dB L_{Aeq} in the principal living room, no more than 30dB L_{Aeq} in the other habitable rooms, and no more than 40dB L_{Aeq} in any hallway, in each building. Noise levels from the mechanical system(s) shall be measured at least 1 metre away from any diffuser.*

Or

(ii) Air conditioning plus mechanical outdoor air ventilation capable of:

- *Providing internal temperatures in habitable rooms not greater than 25 degrees Celsius at 5% ambient design conditions as published by the National Institute of Water & Atmospheric Research ("NIWA") (NIWA, Design Temperatures for Air Conditioning (degrees celsius), Data Period 1991-2000), with all external doors and windows of the habitable rooms closed;*
- *Providing 0.5 air changes (plus or minus 0.1) of outdoor air per hour in all habitable rooms;*
- *Each of the air conditioning and mechanical ventilation systems shall be capable of being individually switched on and off by the building occupants; and*
- *Creating no more than 40dB L_{Aeq} in the principal living room, no more than 30dBA L_{Aeq} in the other habitable rooms, and no more than 40dBA L_{Aeq} in any hallway, in each building. Noise levels from the mechanical system(s) shall be measured at least 1 metre away from any diffuser.*

And

(iii) A mechanical kitchen extractor fan ducted directly to the outside to serve any cooking hob, if such extractor fan is not already installed and in sound working order.

There shall be no exemptions to this rule and the following installation of the measures to meet the above standards the applicant shall provide the Council with a certificate from a suitably qualified independent person or persons approved by the Council, that the installation of those measures has been properly undertaken in accordance with sound practice.

Of the two alternatives, the mechanical ventilation system only option (i) is generally not preferred for the following reasons:

- The size of the required ventilation system (plant and ducts) is large and difficult to accommodate in Medium Density Housing typologies.
- High capital costs associated with providing additional fans over and above providing the minimum outdoor air ventilation race.
- High running cost associated with providing high air change rates.

- High ventilation rates result in higher maintenance costs for filter replacement.
- Does not, on average, provide a level of comfort equivalent to natural ventilation during peak summer conditions. Only air-conditioning would provide this.
- Does not provide winter heating and will result in colder winter temperatures internally when compared with natural ventilation if additional heating is not provided.
- The operation of the ventilation system (different ventilation rates for different conditions) isn't easy to use for occupants.

For these reasons the air conditioning plus mechanical outdoor air ventilation option (ii) is generally preferred.

D3.3.2.3 Building Consent Requirements

Clause G4 of the New Zealand Building Code [23] covers Ventilation and Clause H1 of the New Zealand Building Code [23] covers the Energy Efficiency of the Thermal Envelope. There are no requirements in the Building Code covering Temperature Control for normal residential buildings.

Natural Ventilation

Clause G4 covers both the option of natural ventilation and mechanical ventilation for all types of household units. Generally speaking, all household units have the provision for natural ventilation in habitable spaces and its requirements in the Clause G4 are universal and prescriptive – ie. that the net openable area is not less than 5% of the floor area.

The exception being where household units have only one external wall with opening windows, where cross ventilation is not possible and additional features are required such as:

- provision of trickle ventilation,
- provision of either passive stack ventilators or
- continuous or intermittent mechanical ventilation in the kitchen, bathroom, toilet or laundry.
- limitations on the depth of the space either 6m or 10m depending on the combination of features above

Mechanical Extract Ventilation

Where natural ventilation is not possible due to the acoustic environment, as determined by the Resource Consent requirements, then a mechanical outdoor air system will be required. This should provide as a minimum 0.5 air changes (plus or minus 0.1) of outdoor air per hour in all habitable rooms. This is broadly equivalent to the minimum outdoor air requirement of 10L/s/person as required by NZS 4303:1990 Ventilation for acceptable indoor air quality [74] which is the relevant Standard for mechanical ventilation referred to in NZ Building Code G4.

Similarly, it is usual to provide mechanical air extraction for toilets, bathrooms and laundries and a non-recirculating extract hood over the kitchen hood for more effective moisture and odour removal rather than relying on openable windows. Again NZS 4303:1990 [74] can be used for determining the required minimum extraction rate in toilets, bathrooms and en-suites. This minimum rate is often exceeded for qualitative reasons. Kitchen hoods come in a variety of styles and capacities to suit the hob size. They are invariably noisy at higher speeds which limits there use and effectiveness.

Energy Efficiency

Clause H1 of the New Zealand Building Code [23] sets minimum standards for the energy efficiency of new building work. The methods for proving compliance [75] are outlined in two approved documents; NZS4218:2004 [76] applies for all houses and all other buildings less than 300m^2 floor area. In the case of houses the minimum R-value requirements are stated in replacement tables within NZBC Clause H1. Applying this standard will improve thermal comfort and reduce the need for any active heating and cooling.

The standard sets out three methods for meeting the required levels of energy efficiency; the 'Schedule, Calculation and Modelling' methods. The schedule method is highly prescriptive citing minimum R-values for each building element and is limited to buildings with Window-to-Wall ratios (WWRs) below a certain limit. The calculation method uses an area weighted heat loss calculation which allows greater flexibility through the use of lower R-values in some areas with the combination of higher R-values in others. The modelling method requires the estimated energy requirement for conditioning the building to be calculated using computer simulation.

For medium density housing with usual WWRs in the range of 30-50% the schedule or calculation methods are normally used

The thermal resistances of the building elements in the reference building were taken from replacement Table1 in the Clause H1 compliance document [75]. These values overrule those in NZS4218:2004 [76]. In addition, the R-values in replacement tables 3 and 4 are used where applicable. These are shown in Table 5 below:

Table 5: Required /Reference Minimum R values-values

Building Thermal Envelope Component	Minimum R-values (m^2.°C/W) Zone 1
Roof	R 2.9
Wall (non-solid)	R 1.9
Wall (solid)	R 0.8
Floor (solid)	R 1.5
Floor (heated)	R 1.9
Glazing (limited to 30% WWR)	R 0.26

The glazing required by the reference standard is generally double glazed thermal insulated glass units. Standard 6/12/6mm thermally insulated glass units do not have a particularly high acoustic performance. The small air cavity present in thermal double glazed units causes a significant dip in acoustic performance at 160 – 200 Hz. In high noise areas it can be necessary to increase the increase the glazing pane thicknesses or the cavity size. The use of laminated glass is also often required. However there is a limit to the overall thickness that can be achieved within standard frames. And therefore increasing glass thickness often requires a corresponding reduction in air cavity. Sometimes significant increase in glazing thickness and cost only achieve a minor increase in overall performance. Achieving very high levels of performance requires either thick laminated glass or large air cavities (>50 mm). The cost of high performance acoustic, double glazing being quite prohibitive.

The Building Code represents minimum standards for energy efficiency and higher standards and better practice can be used by adopting the Homestar rating system which generally seeks to improve upon the minimum code levels of performance. Code represents a 3-4-star level on the 10 star Homestar range. The proposed Auckland Unitary Plan sought to mandate a minimum 6 star Homestar Standard for all household units in the Auckland Isthmus. However, this has not subsequently been adopted in the Operative Plan.

Thermal efficiency can be improved by changing the thermal insulation, thermal mass adjusting the extent of glazing, using thermal curtains, making the building more airtight etc. and related to the Homestar thresholds.

Adopting these higher standards will significantly reduce or eliminate the need for any active heating and cooling which would also have acoustic benefits.

D3.3.2.4 Thermal comfort

The requirements for thermal comfort are not covered directly in the NZ Building Code other than minimum temperatures for early childhood and elderly care buildings

Similarly, it is not unusual for no active heating and cooling systems to be provided in medium density housing and to place the responsibility on the building owner or tenant to provide any active heating arrangements. These can range from plug in electrical heaters, heat pumps, wood burners, gas fired central heating systems etc.

The comfortable internal temperature range has been defined as being between 18 and 24°C by the World Health Organisation (WHO).

For well-designed household units, the internal temperature should be within this preferred range for 70-80% of the year without the need for any active heating or cooling. This can be achieved by a combination of the following features that are applied in an integrated way:

- Appropriate standards of thermal insulation, generally better than code.
- Good standards of glazing either double glazing as per code or higher standards particularly in cooler climate zones, including low e coatings and argon fill.
- Relatively modest window wall ratios (WWR) in the range of 30-50%
- Reasonable levels of weathertightness.
- Adequately sized, well distributed and operable natural ventilation provisions.

Sales of residential air source heat pumps in New Zealand houses are growing rapidly mainly due to their convenience, energy efficiency and relatively low cost. There is also an increasing trend in standards of heating and cooling in houses with a shift away from little or no form of heating being provided. Also a move away from traditional energy forms such as portable and electric heaters and wood burners. Heat pumps also provide the flexibility for cooling and dehumidification in hot and humid weather with resulting energy use.

Issues with heat pumps include:

- Noise from indoor and outdoor units. This can be mitigated by correct selection and sizing.
- Location and aesthetics of both indoor and outdoor units.
- Increased energy use due to the ability to both heat and cool/dehumidify
- Use of HFC refrigerants which will be phased down as a result of the Kigali amendment to the Montreal Protocol. R32 is the

only transitional refrigerant available presently for residential heat pumps in response to this amendment. HFCs while having zero ozone depleting potential have high global warming potential if released into the environment.

D3.3.2.5 Particulate Matter

Particulate matter (**PM**) is an air-suspended mixture of solid and liquid particles from both human and natural sources. PM is normally classified by size (PM_{10} includes particles of < 10 µm diameter, and $PM_{2.5}$ < 2.5 µm). PM_{10} particles are coarser. Due to their size, they can be intercepted and filtered by the nose and throat. Finer $PM_{2.5}$ particles may pose a greater risk than PM_{10} particles as they can penetrate into the deepest parts of the lung. Sources of $PM_{2.5}$ comprise soil particles tracked in from outside[2], a mix of organic material from 'personal clouds' comprising skin flakes and other bio-effluents, clothes fibres, possible condensation of VOCs, and calcium particles from building deterioration. The other half comes from outside and includes minerals from hard surfaces, and from road traffic.

Generation and re-suspension of these particles is a function of indoor/outdoor movement, and activity levels in the space. Indoor levels can be higher than outside, and sometimes significantly higher.

Strategies to reduce PM levels include good ventilation, cleaning and using well-maintained HEPA vacuum cleaners, and the use of entry/exit mats to mitigate dirt tracking.

Windows used predominantly for natural ventilation should also be oriented away from busy roads/streets wherever possible so as to minimise the effects of both noise and pollutants on the internal environment.

In urban locations where the ambient acoustic environment requires mechanical ventilation, systems should be provided with suitable air filtration. The minimum filter standard should be G4/MERV 7–8 [70]. However, the filtration shall also be related to the nature and actual levels of pollution in the outdoor air and should be selected in terms of atmospheric dust spot efficiency, arrestance, and dust holding capacity, noting the potential risks identified for particle sizes <2.5 microns

D3.3.2.6 Market Research - What Homeowners Want

The results from the annual Homestar / realestate.co.nz survey in Table 6 below show a rising preference for homes with high levels of environmental quality that are warmer, drier, more energy efficient, better designed and equipped and are either located in quiets streets or have a high standard of acoustics.

The Table illustrates a move away from the traditional aspects of location and appearance towards performance and designing the household unit from the inside out.

Table 6: What Homeowners want – Market Research by Realestate.co.nz and NZGBC [media release Dec 2014] % of respondents to survey rating features as 'important' or 'very important'

	2014 results	2013 results	2012 results
Orientated to maximise the sun	91%	86%	87%
High level of insulation	90%	82%	76%
Off-street parking	76%	75%	73%
Ample storage space	76%	72%	71%
Located on a quiet street	74%	69%	69%
Covered car parking (garage/carport)	73%	73%	74%
Energy-efficient features - e.g. LEDs, double glazing	72%	49%	51%
Number of bedrooms (3 or more)	69%	74%	74%
Indoor-outdoor flow	69%	69%	70%
Outdoor entertaining area	63%	65%	65%
Open-plan living	58%	55%	55%
A large section/garden with room for fruit and vegetables	54%	55%	53%
Close to amenities, e.g. schools, medical care, supermarket etc.	50%	47%	48%
A home built with sustainable or environmentally friendly materials	48%	36%	33%
Attractive updated or gourmet kitchen	47%	51%	51%
Renewable energy, e.g. solar PV panels or solar water heating	45%	n/a	n/a
Close to public transport	42%	29%	31%
Large or walk-in wardrobes	41%	42%	44%
Water-saving features e.g. rain water tank	37%	29%	26%

D3.3.2.7 Climate Change Effects

The Ministry for the Environment's Climate Change Projections for New Zealand (2016) conclude that climate change effects will result in higher temperatures, with greater increases in the North Island than in the South, and with the greatest warming in the North East. The amount of warming in New Zealand is likely to be lower than the global average. Warming will be greatest in the summer season, and least in winter and spring. Temperature extremes are anticipated to change significantly by the end of the century, with maximum temperatures of 25˚C or more predicted to double or quadruple in frequency.

Heating and cooling requirements are therefore likely to change over time, with greater reliance on active cooling in warmer regions. This response should be viewed in conjunction with the anticipated life cycle of residential heating and cooling systems – typically 10 to 15 years – and also with the need to minimise greenhouse gas emissions in the short to medium term.

Building design should therefore seek to both mitigate and adapt to climate change.

Mitigation strategies might include;

- Maximising passive design strategies including the use of natural renewable energy - natural light and natural ventilation. The success of these strategies will depend on thermal insulation, good glazing design, WWR and thermal mass
- Minimising the size and use of any residual active heating and cooling and lighting and making any provisions energy efficient
- Avoiding the use of fossil fuels.

Adaption Strategies might include.

- Designing buildings to accommodate more frequent and higher summertime temperatures, less quantity and better performing glass, sun shading and increased thermal mass.

D3.3.3 QUALITATIVE EFFECTS OF HVAC EQUIPMENT

There is a reasonable range of acoustical quality of HVAC equipment suited to residential use that is available from the market. Selection between the best and worst performing equipment has measurable differences in cost and energy/acoustic performance.

Selection has tended to be at the lowest cost level at the Medium Density Housing quality level mainly due to lack of consideration of the options available.

Heat pumps are often also retrofitted by household owners with little recourse to technical advice or consideration of potential impacts on their neighbours or on their visual effect on the building.

Heat Pumps

Heat pump advertising can create confusion as the quoted noise levels are often for the smallest capacity units operating on the lowest fan speed.

In general terms, noise is directly related to the amount of air the heat pump is moving. To produce more heat, bigger capacity units need to move more air than smaller units, so generally a bigger unit will make more noise than a smaller one.

As sound is related to the amount of air movement, a heat pump will produce more noise on high fan speed than it will produce on low fan speed.

High fan speed most often occurs straight after starting up, when the heat pump is trying to deliver maximum capacity to get the room to temperature as soon as possible. As the room gets closer to temperature the fan should slow down, reducing the amount of sound produced. A correctly sized heat pump should have the room temperature under control, and the fan starting to slow down within approximately 15 minutes of starting up. After that a lower fan speed should be able to keep the room temperature constant. This is why it is very important to have a correctly sized heat pump, as an undersized unit will be louder for longer.

If the heat pump unit is in a room with hard surfaces and few furnishings it will seem noisier than the same unit in a room with more furnishings, drapes, etc. The distance away from the heat pump also effects the amount of sound perceived, so the mounting position within the room is important.

Outdoor units associated with existing medium density housing are becoming ubiquitous and there appears to be little or any enforcement of potential boundary noise issues. Luckily, they are more often used at present in winter months for heating when most people have their windows closed.

Proximity to boundaries and bedrooms of outdoor units needs to be given greater consideration. With inverter compressor outdoor units correct sizing is again important so that the outdoor units operate at lower speeds and noise levels for a considerable period of their operation.

Fans

Most manufacturers can provide either a standard mixed flow fan having a higher noise level or a quieter 'acoustic' model.

Actual fan noise level will depend on the construction of the ceiling they are above and the location and sizing of associated grilles/louvres/cowls.

The control arrangements of the fans are also important. Whether they run continuously or intermittently. And if intermittently whether there is a delay on and a delay off arrangement in conjunction with light switching. Or if not light switch controlled whether there is an on/off switch and a speed controller so the occupier can either maximise or minimise ventilation and noise depending on activity.

D3.3.4 CHECKLIST OF INDOOR AIR QUALITY AND TEMPERATURE CONTROL FEATURES FOR MEDIUM DENSITY HOUSING

The following is a preliminary checklist on potential air quality and temperature control features for Medium Density Housing. A set of costed Minimum, Better and Best measures for Medium Density Housing could be developed further in conjunction with acoustic considerations to better inform industry and consumers on their qualitative options.

BUILDING FORM

- Maximise dual or corner aspect design to increase utilization of natural light and ventilation.
- Limit depth of space to 2-2.5 times the height in single aspect spaces and 4-5 times the height in double aspect spaces.
- Maximise aspect of living spaces towards the sun whilst avoiding summer over-heating by simple sun shading.

BUILDING FABRIC

- Select building fabric to maximise passive ventilation and temperature control. Target 80% of the year. This will limit any need and potential operation of mechanical systems.
- Limit window wall ratio (WWR) to between 30 and 50%.
- Encourage high levels of thermal insulation better than code.
    - Roof R > 4.0
    - Walls R> 2.8
    - Floor R > 3.1

- Use double glazing in Climate Zone 1, Low e double glazing in Climate Zone 2 and Low e argon filled double glazing in Climate Zone 3.
- Consider use of thermal mass to limit overheating in conjunction with acoustic separation requirements.

VENTILATION

- Use natural ventilation wherever practicable.
- Where mechanical ventilation is required for acoustic reasons provide minimum outdoor air quantity of 10v/s/person (nominally equivalent to 0.5 ACPH).
- Where subject to road traffic noise and pollutants mechanical air supply should be filtered to GA/MERV 7-8 standard or higher.
- Toilets, bathrooms and en-suites to be provided with mechanical extract ventilation to avoid reliance on openable windows and to maximize capture of moisture.
- Fans serving toilets, bathrooms and en-suites to be provided with either light switch control with time delay on and off or a separate switch with rotary speed controller.
- Select mechanical extract and outdoor air fans for lower noise/better quality.
- Design associated ductwork systems to meet appropriate noise levels.
- Consider a heat recovery ventilation system in cold climate zones.

TEMPERATURE CONTROL

- Where natural ventilation is precluded for acoustic reasons, provide a suitably sized heat pump in each level of a 2-storey household unit or in the main living space in a single storey household unit or apartment.
- Heat pump indoor and outdoor units to be selected based on best acoustic and energy efficiency criteria.
- Consider Heat pump outdoor unit's location as follows particularly in relation to bedrooms and neighbours. Potential locations could include:
  - In yard and in relation to boundary.
  - On balconies in purpose designed proprietary enclosures.
  - Integrated into balcony design e.g. as part of planter.
  - Integrated into a separate service balcony in addition to the main balcony.
  - At roof level with suitable access and restraint and in accordance with 'Safety in Design' principles.
  - In car park if suitably ventilated.
- Select heat pumps with regard to refrigerant type and phase down of HFC refrigerants to minimise global warming effects. Current option R32.

GENERAL

- Develop a set of costed Minimum, Better and Best measures for Medium Density Housing in conjunction with acoustic considerations to better inform industry and consumers on their qualitative options.

D3.4 NATURAL LIGHTING

With typical facade constructions the windows are the weakest point in the sound insulation of the building envelope. The location, design and size of the windows has a direct effect on the overall acoustic performance. However reduction in glazing area, to increase sound insulation performance, is not often possible or practicable due to the requirements for natural light.

D3.4.1 CURRENT REQUIREMENT FOR NATURAL LIGHT

New Zealand Building Code clause G7 Natural Light [23] requires 30 lux at the floor level for 75% of the year. The code sets out requirements for vertical windows in external walls and a glazing transmittance of 0.7. It states that vertical windows shall have a window area of no less than 10% of the floor area. This equates to approximately 33 lux at floor level for 75% of the year. Window head heights are required to be at least half the room width for windows on the same side or adjacent sides of a room and one quarter the room width for windows on opposite sides of the room.

D3.4.2 TREND TOWARDS LARGE WINDOWS AND DOORS

There is a trend towards the use of large floor to ceiling windows and doors which are desired over small window openings for the unobstructed views and volume of natural light they provide to interior spaces.

Homeowners want visual access to the exterior and plenty of natural daylight and advancements in window energy performance make this cheaper and more accessible. If designed properly, large well-positioned windows can help heat a home through passive solar gain in the winter and sun shading cad control heat gain in summer.

D3.4.3 APARTMENT TYPOLOGIES

Terrace housing and double loaded apartments mean that maximum natural light via large windows is required from both end walls of the building. This means that well performing acoustic windows and glazing play an important role in the design of high quality acoustics in medium density housing.

D3.4.4 ARTIFICIAL LIGHTING

The use of recessed downlights instead of surface mounted fixtures can create an acoustic weak point due to the penetration into the roof cavity.

D3.5 WATER-TIGHTNESS

Achieving adequate water tightness is of critical importance to successful MDH building design. In some areas water-tightness and acoustic requirements are complementary. In other areas, the requirements necessitate alternative acoustic solutions to be developed.

D3.5.1 CURRENT REQUIREMENT FOR WATER TIGHTNESS

The New Zealand Building Code clauses E1 Surface Water and E2 External Moisture [23] give performance criteria that buildings must meet. E2 requires building exteriors to adequately resist the penetration and accumulation of moisture from the outside.

Compliance with E2 has led to a trend in ventilating façade cladding via a vented cavity. The presence of small air cavities in a wall build-up can cause resonances that can significantly reduce low frequency sound insulation performance. Sound transfer via a ventilated cavity can also be problematic

D3.5.2 USE OF FLOATING FLOORS

The use of floating floors to isolate noise and vibration in New Zealand is a relatively new addition to the apartment construction industry. There is currently a lack of awareness of this acoustic option and a lack of detailed solutions available in the industry particularly around the detailing of waterproofing in wet areas.

Floating floors are common in Europe and there are multiple systems available. Some examples use dry sheet materials and there are various different concrete systems in use such as pre-cast or poured concrete laid on a waterproofing layer or jacked up via units cast into the slab.

There is some resistance within the industry to using this system as there is a cost premium associated with it.

D3.6 SUSTAINABILITY

This section covers broad areas of considerations – see section D3.3.2 “Temperature Control and Indoor Air Quality” for more details

D3.6.1 USE OF EXTERNAL PRIVACY AND SUN SHADING SCREENS

Energy efficient architectural design that reduces a buildings energy consumption is a fast growing global trend. The design of appropriate external sun shading can passively reduce excess solar radiation that might otherwise enter the building. Sun shading can be integrated into the architectural design of the external façade to add visual texture and interest to residential buildings.

The presence of wind and the use of external shading elements for sun and privacy can sometimes result in whistling and banging noises which are disturbing to occupants of the building and also neighbouring buildings.

D3.6.2 VENTILATION

The use of natural ventilation to minimise energy use is a common objective in modern buildings. This is most effectively achieved by using passive solar design which shades windows and walls from heat gain and encourages airflows that distribute heat or ‘coolth’ through the building.

D3.6.3 THERMAL MASS

Thermal mass is the ability of a material to absorb and store heat energy. A lot of heat energy is required to change the temperature of high density materials like concrete, bricks and tiles therefore they have high thermal mass. Thermal mass can provide good acoustic insulation between rooms and tenancies, or from outdoor noise, although it may also reflect sound and transmit impact noise.

D3.7 ARCHITECTURAL TRENDS

There is a current trend in apartment design towards the use of hard internal finishes and the exposure of the structure and services in a building. The Industrial Style refers to an aesthetic trend in interior design that takes cues from older industrial spaces. Components used in an industrial style include wood, building systems, exposed brick, industrial lighting fixtures and concrete. Coupled with this is the desire for architectural "honesty", whereby materials and structural elements are left exposed.

It is common to use timber throughout the interior as wall and ceiling linings, but more commonly on the floor as timber strip flooring.

Exposed, hard internal surfaces reduce acoustic absorption and can result in structure borne noise including footsteps on hard floors, the scraping of chairs and the dropping of objects.

D3.8 ECONOMIC

Economic constraints are obviously a major consideration in any MDH design. Because of the subjective nature of people's response to noise and the multitude of different building circumstances, economic assessments in relation to acoustic quality are not necessarily straight forward, but this section looks at a few considerations.

One key reference in relation to this is the cost benefit analysis performed as part of the 2010 proposed updates to the Building Code Clause G6, Appendix C of [24]. This analysis (by Infometrics in 2007) looked at the costs and benefits of changing the NZ building code to higher levels of acoustic performance in the proposed Clause G6. Similar principles apply where buildings are built to exceed the minimum building code levels, with the exception of compliance change requirements.

As discussed in the summary of the cost benefit analysis, acoustic concerns have a lower status, from a safety perspective, than fire or structural requirements, as in general houses are quiet enough not to generate obvious hearing damage. However the long term health effects of noise annoyance can be significant as also outlined in the reasoning for the Proposed Clause G6 changes, pg 8 of [24]

Including better noise insulation and design in broad terms can provide some the following pros and cons

<u>Pros</u>

- **Resident Health:** reduced health effects from stress, insomnia and annoyance – good for the resident and reduction in health costs (eg hospital, GP visits, time off work).
- **Improved wellbeing:** better resident satisfaction level, reduced nuisance value, from a healthier internal environment. Hard to quantify.

- **Resale:** an added selling point for resale, potential increase for resale price.
- **Reduction in noise complaints –** improved neighbourly relations, less complaints for councils and body corps, and less potential lawsuits against developers and architects.
- **Marketing opportunity:** a better outcome for residents can be useful for future marketing by the developers and designers
- **Future proofing:** external noise sources and neighbours change, so even if there is not an issue now, it may help for future noise increases.

Cons

- **Increased building costs** – additional acoustic insulation and structural isolation requirements can increase development cost and ultimately the purchase price
- **Over engineering** – because of the subjective and variable nature of residents' response to noise, in some situations the extra cost of improved acoustic quality may not be required by some residents, and could be an "over-engineered" solution

Retrospective mitigation of noise issues is usually much harder than incorporating acoustic considerations at the concept and design phase. Encouraging the incorporation of acoustic considerations at the building design phase in an integrated approach, should lead to better quality MDH. This ensures solutions that are optimised to meet as many needs as possible for the minimum cost. E.g. a slightly more expensive structural solution may offset higher acoustic, thermal or fire performance costs, or using materials such as appropriate insulation that meets multiple needs.

Careful monitoring of workmanship during construction should mean the full benefit of the design solution is obtained. However if the solution is not built to specification (eg air gaps not sealed, bridging isolation layers etc) the performance can be significantly reduced, negatively affecting the cost benefit of the solution.

Changes to Clause G6 itself would introduce additional costs but also provide some opportunities

- **Education:** Costs involved with educating industry on new rules, metrics and compliance – including developers, engineers, architects, acousticians, building consent authorities / Councils, government bodies, builders and installers, manufacturers. An opportunity to raise awareness of acoustic considerations and available solutions so they can be better incorporated.
- **Compliance:** Changes to methods for checking and enforcing new requirements would impact on building consent authorities, councils, acousticians and the cost of additional testing for compliance would add to construction costs
- **Products:** Developing and disseminating new methods for testing, and improving products to meet the adjusted code. Also losses associated with products that no longer comply.
- **New products:** Opportunity for manufacturers and importers in relation to new products.

Marketing

Depending on how a new MDH development is marketed, purchasers of the apartments may have overly high expectations of the acoustic performance. Even in instances where the acoustic performance achieved is of a higher standard than the legal minimum, this does not mean that noise from other areas will be inaudible. There is no such thing as "soundproof" construction and the use of the term "soundproof" must be avoided at all cost in any sales literature or other claims related to the project.

Rating Systems

As there is additional cost in increasing the acoustic performance of an apartment over minimum building code requirements, then perhaps there is an opportunity to increase the incentive to do this. At present there is no simple way to identify how well above the building code a building performs.

In Mann et al's paper on proposed changes to Building Code Clause G6 [27] they note the potential benefit of a classification system to help understand the noise insulation performance of a property. This could be of benefit to owners and potential buyers and also for developers marketing a property.

In Australia, the AAAC (Association of Australasian Acoustic Consultants), use a star based acoustic rating system [31] for various aspects of a residential building's acoustic performance including for external noise, building service noise, as well as rating sound insulation and impact isolation. Each aspect has a 1-star to 6-star range from below minimum performance levels (for assessing older housing pre current code), up to luxury standards considered suitable for expensive penthouses.

The AAAC only changed in 2016 from being an Austra<u>lian</u> Association to an Austra<u>lasian</u> Association, but application of the various guidelines have not necessarily yet been approved as applicable in NZ by NZ consultants. However the idea is an interesting one for NZ MDH improvement.

The paper [77] by Berardi and Ramussen gives an interesting discussion comparing European classification schemes with the situation in the US where the idea is yet to be adopted.

APPENDIX E INFORMATION RESOURCES

This appendix is broken down into the following sections

- Acoustic standards
- Public Resources: NZ and International design guides and other information tools available to industry
- Academic Research: Details of ongoing research and research facilities
- Acoustic related organisations

Most of this information was gathered during the project's Stage 1 literature review, with some later additions identified.

E1 Key Acoustic standards

The following table outlines the most relevant standards, both NZ and internationally. (NZS – New Zealand Standard, AS- Australian Standard, BS- British Standard, EN- European standard, ISO-International Organization for Standardization standard, ASTM- "ASTM International" standard, (pre 2001, ASTM=American Society for Testing and Materials).

Standard Number	"Title" and extra info
ASTM E413	"Classification for Rating Sound Insulation"
ASTM E336 and E90	E336 "Standard Test Method for Measurement of Airborne Sound Insulation in Buildings" – latest version 2016 E90 "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements" latest version 2016
ASTM E492	"Standard Test Method for Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies Using the Tapping Machine"
ASTM E989	"Standard Classification for Determination of Impact Insulation Class (IIC)"
AS/NZS ISO 717 (1996 version also known AS/NZ 1276)	"Acoustics - Rating of sound insulation in buildings and of building elements" 717-1 (AS/NZS 2004, ISO1996) - Airborne sound insulation 717-2 (ISO 2013) – Impact sound insulation
ISO 16283 (New version of field measurement parts of the old ISO 140 series, which **NZS 140** series is based on)	"Acoustics -- <u>Field</u> measurement of sound insulation in buildings and of building elements" – ISO 16283 -1:2014 Airborne sound insulation ISO 16283-2:2015 Impact sound insulation ISO 16283-3 2016 Façade sound insulation
ISO 10140 (New version of the lab measurement parts of old ISO 140 Series)	"Acoustics -- <u>Laboratory</u> measurement of sound insulation of building elements" – suite of standards ISO 10140 -1: 2016 Application rules for specific products ISO 10140-2: 2010 Measurement of airborne sound insulation ISO-10140-3: 2010 Measurement of impact sound insulation

	ISO- 10140-4:2010 Measurement procedures and requirements
BS EN 12354 also to become ISO 12354 (replacing ISO 15712)	"Estimation of acoustic performance of buildings from the performance of elements" British/European standard being adopted internationally. This series includes parts for airborne and impact transmission between rooms, airborne transmission through façades, service noise and room absorption. New versions for parts 1-4 are currently in review
AS/NZS 2107:2016	"Acoustics - Recommended design sound levels and reverberation times for building interiors"
NZS 6800s series NZS 6801:2008	"Acoustics - Measurement of environmental sound"
NZS 6802:2008	"Acoustics - Environmental noise"
NZS 6803:1999	"Acoustics - Construction noise"
NZS 6806:2010	"Acoustics - Road-traffic noise - New and altered roads"
ISO 80000-8:2007	"Acoustics" - gives names, symbols and definitions for quantities and units of acoustics
(ISO19488)	In development – "Acoustic classification scheme for dwellings" grades of performance for different aspects of building acoustics

E2 Public Resources

This section includes a collation of publicly available design guides and resources, identified primarily during the Stage 1 literature review but with some additional resources identified throughout the project. This aims to help address the BRANZ question re what current information exists.

These are information resources available for use immediately by the those in the building industry, rather than the academic research papers considered in section E3 looking at future developments. Often acoustic considerations are one section within broader design guides.

NZ examples are given first, followed by overseas examples – which may require a little further interpretation to match with NZ requirements.

In some cases, descriptions and web links are provided rather than formal references.

E2.1 NEW ZEALAND EXAMPLES

There are several different types of sources of acoustic design information. These include information provided through the government agencies, through industry associations, and through individual commercial manufacturers and consultants.

E2.1.1 PUBLIC ORGANISATIONS

Examples of publicly available information provided through the NZ government and independent government backed organisations include

- **MBIE - Building Code information** – The building code Clause G6 compliance document [5] includes details of the building code clause, Acceptable Solutions and Verification Methods (see section D2.1). The MBIE website also includes information on 'Determinations' relating to interpretations of the building code where there is some uncertainty.

www.building.govt.nz/building-code-compliance/g-services-and-facilities/g6-airborne-and-impact-sound/

- **BRANZ Testing and Appraisals:** When manufacturers want to have their products and systems checked for compliance with the NZ building code, BRANZ can organise testing and produce Appraisals which can be publically viewed http://www.branz.co.nz/aboutappraisals. Some building wall/floor systems include relevant testing for building elements for STC/IIC/R_w ratings and appraisals of how they compare with Clause G6 / NZ building code. Some appraisals also relate to the Australian Building Code.
- **BRANZ Studies**, BRANZ also organises various building studies, which are available through their website. A key acoustic study noted as of use for designers was "Optimised wall-to-floor junctions in multi-storey, multi-residential light timber-framed buildings. System Number: SR208" [72] http://www.branz.co.nz/cms_display.php?st=1&;sn=18&;pg=17311
- **BRANZ – Level.org.nz** the authority on sustainable building also provides some broad advise on noise control and design. http://www.level.org.nz/passive-design/controlling-noise/
- **BRANZ publications**: Relevant articles in past "Guidelines" newsletter and "Build" magazine were noted as helpful for learning about acoustics. Articles are available to download free from www.branz.co.nz/guideline and www.buildmagazine.org.nz, with a useful search functionality
- **NZTA (New Zealand Transport Authority) Noise info and calculators:** www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/noise-and-vibration
This includes a range of information on the assessment of noise, use of barriers, treatment of buildings, construction noise, research and documentation on traffic noise, planning including reverse sensitivity. There is also an online traffic noise calculator which allows for different traffic, road surface / slope, relative building position, as well as a calculator for approximate indoor noise for different façades.
- **NZ standards** : Acoustics standards adopted in New Zealand legislation and for acoustic measurements, are not available for free except to view in person from some libraries. However, they can be purchased from the NZ Standards Authority, http://www.standards.govt.nz/

E2.1.2 MANUFACTURER GUIDES

One of the most detailed sources of design advice comes in the form of system manufacturer manuals. It is in the manufacturer's interest to provide plenty of information on the acoustic performance of their wall and flooring systems, as this provides designers with a quick way to help them meet building code requirements. They also often include general acoustic principles and offer some guidance.

In New Zealand there are several key manufacturers producing guides specifically relating to acoustic performance of wall and floor/ceiling systems. These are usually available both in print and online form – with the online manuals containing the most up to date information. Examples include:

- **Winstones Wallboards: GIB** Noise Control System handbooks, https://www.gib.co.nz/systems/gib-noise-control-systems/ The site includes technical information on noise control systems and design advice for designers, specifiers and builders for various levels of acoustic comfort and includes junction information. Also their inter-tenancy wall systems https://www.gib.co.nz/systems/gib-intertenancy-barrier-systems/
- **HARDIES:** Fire and Acoustic Design Manual http://www.jameshardie.co.nz/assets/Uploads/downloads/Fire-and-Acoustic-Design-Manual-Nov-2015.pdf for their timber and steel frame systems.

- **Speedwall** - intertenancy wall manufacturer guides and spec sheets, available through their library http://www.speedwall.co.nz/library/, along with related products such as sealants. An example of a full system design guide is the brochure "SPEEDWALL® INTERTENANCY SYSTEMS 2016 FOR TERRACED HOUSING AND APARTMENTS" http://www.speedwall.co.nz/assets/resources/Speedwall-Intertenancy-Systems-2016.pdf
- **USG Boral guides and systems**
  Their resource centre https://www.usgboral.com/en_nz/product-resources-and-tools-from-usg-boral/the-resource-centre/document-finder.html can link through to various acoustic related products and information guides such as "USG Boral plasterboard Installation Manual NZ-PB105-1" and "USG Boral Partiwall- installation manual – NZ PB200/2", plus other ceiling and wall systems. Some guides are Australian based such as "ACHIEVING FIRE & ACOUSTIC COMPLIANCE IN MULTIRESIDENTIAL CONSTRUCTION"
- **Rondo:** Professional Design Manual - Acoustic wall and ceiling systems Sep 2015 includes systems compliant to both the NZ and Australian Building Codes.
  http://rondo.co.nz/index.php/products/acoustic-assemblies

Manufacturers of acoustic insulation, tracks, isolation clips, acoustic rated windows etc. will also provide technical specifications and information.

There are also some sites which collate manufacturer solutions such as www.ArchiPro.co.nz which includes some acoustic related product listings.

E2.1.3 INDUSTRY ASSOCIATION GUIDES

Industry Associations often try, as part of their collaborative focus, to pool knowledge relevant to their field. Appendix E4 lists a number of these groupings in New Zealand with a connection to residential building industry. A few examples of acoustic related guides provided by such groups include

- **NZ Concrete Masonry Manual – Section 2.4 Acoustic Performance** (NZ Concrete Masonry Association Inc and CCANZ August 2013) http://www.nzcma.org.nz/document/279-25/NZCMA_MM_-_2.4_-_Acoustic_Performance.pdf general information plus an example of a Transmission Loss test report for a masonry wall.
- **CCANZ** (Cement & Concrete Association of New Zealand) website has links to various papers and guides with a concrete / cement focus, including some related to sound transmission. e.g. CCANZ Apartment design guide 2014 with a few pages on acoustic design, at http://www.ccanz.org.nz/files/documents/4f553995-3dd0-41cd-8650-4f7d7d4ec11f/CCANZ_Apt_Design_Guide_2014.pdf
- **NZWood**, has a few handy general acoustic design guidelines at http://www.nzwood.co.nz/category/learning-centre/timber-performance/acoustic/ based on the acoustic sections of the *Timber Design Guide, 2007 produced by the NZ Timber Industry Federation NZTIF (*www.nztif.co.nz *)*
- **Green building council – Homestar tool**
  https://www.nzgbc.org.nz/homestar

E2.1.4 MODELLING SOFTWARE

Another avenue for designing building elements, is to use modelling software to test the potential acoustic properties of combinations of materials. In general it is much easier to model the behaviour of simple building elements (eg a wall or floor) rather than complex combinations (eg combined wall, floor and ceiling with all junctions).

Sound insulation modelling software allows you to virtually construct a wall or floor/ceiling cross section from various building products (eg timber, gib, isolation clips, insulation, concrete slab), and predict the sound insulation properties of the total element. However it is important to note that the results are not infallible and a certain degree of expertise in building design is required for proper interpretation.

A NZ specific example is:

- **INSUL** "A quick & accurate tool for predicting the sound insulation in walls, floors and ceilings" – www.insul.co.nz (commercial product produced by Marshall Day Acoustics) incorporates test data for most NZ based acoustic products and building materials

Section E3.2 looks at current research into prediction and modelling tools, which could be incorporated into building acoustic modelling software in future.

E2.2 INTERNATIONAL EXAMPLES

International acoustic related design guides and manuals, along with their dissemination mechanisms, may be useful for comparison and possible adoption in NZ.

Team experience and an online search methodology has been applied to search design guides and manuals for MDH acoustic performance at an international level. International examples are presented in tabular form, however not all of the international construction details may be appropriate to the NZ context or meet the NZ building code requirements.

Covered here are sections on 1) information sources, 2) Australian Examples, 3) international examples

E2.2.1 SOURCES

Acoustic design information and information dissemination strategies appear to be widely available internationally. However, MDH specific design guides, manuals and details are often combined within wider design guides for more general building's types (i.e. hotel, education, office, healthcare, etc.) or design topics (i.e. thermal insulation, fire protection, indoor environmental quality, sustainability).

The information is produced and/or made available by various public and private organisations and initiatives. National governments, city councils, public bodies, research institutes and non-profit organisation have published or contributed locally based design guides, manuals or in many cases minimum requirements and recommendations.

Building material, product and system manufacturers and suppliers; along with industry association and private consultancy and service providers, are also providing general acoustic advice and /or design guides for specific products use and building applications (among them MDH).

Acoustic consultancies will also often provide information on general acoustic principles as part of helping people understand the need for considering acoustics.

All the information certainly contributes to supporting local, national, and international building construction stakeholders in achieving good quality acoustic design and building developments.

The tables below present and reference examples of international, English language, acoustic design, manuals and tools related to MDH developments.

E2.2.2 AUSTRALIAN EXAMPLES

The Australian building code is different in many ways to the NZ building code but there is a lot of communication between the NZ and Australian building industries, especially in terms of available products, testing facilities, and Australasian groupings. NZ tends to more light weight timber construction in many circumstances, in part due to availability of timber but also due to NZ's higher seismic requirements. Note the Australian Building Code uses the ISO ratings (e.g. R_w, $D_{nT,w}$, $L'_{nT,w}$) rather than the ASTM ratings used in NZ (e.g. STC, FSTC, IIC)

Australia has a number of useful types of design guides and information sources that could be adoptable in NZ with adaption to the NZ Building Code and NZ practices or materials. Individual States (eg New South Wales, Victoria) may also have specific variations on the code and provide localised information:

Building Code of Australia (BCA) The BCA is produced and maintained by the Australian Building Codes Board (ABCB), with details provided in the National Construction Code (NCC) and available via the ABCB website http://www.abcb.gov.au/Resources/NCC . This includes various acceptable forms of construction for key building elements and discussion

ABCB – non-mandatory handbook "Sound Transmission and Insulation in Buildings" –acoustic design principles, mostly from a generic perspective in the main chapters 2, 4 and 5 https://www.abcb.gov.au/Resources/Publications/Education-Training/Sound-Insulation, with Chapter 3 outlining general BCA principles for compliance only. A useful compliment to the NCC details.

AAAC guideline for apartment and townhouse acoustic rating 2010: Association of Australian Acoustic Consultants (AAAC) guide downloadable from http://www.aaac.org.au/au/aaac/downloads.aspx when you give your email address. This includes details of the AAAC Star based 'Acoustic Rating' system, for rating the acoustic performance of housing (old and new), including separate star ratings for: sound insulation of walls, floors/ceilings; impact isolation for floors/walls; external noise intrusion; building services noise.

Owners Corporation Network Guide – Noise in Strata Buildings http://www.ocn.org.au/guide/noise-strata-buildings: An overview of sound and noise control principles, sound insulation requirements and how they apply for strata housing for the information of owners and residents. "OCN was established in 2002 when representatives of a number of large, recently completed strata buildings found they had common challenges – building defects, expensive insurance, noisy neighbours - and wondered how best to manage the complex beast called 'cooperative living'." -www.ocn.org..

Strata title is a form of ownership devised for multi-level apartment blocks and horizontal subdivisions with shared areas, but most of the noise information is applicable in broader circumstances, and it also raises some of the social and building management issues around noise when living in close proximity.

Wood Solutions - independent organisation providing timber building advice in Australia- some guides are specifically acoustics focused e.g.

http://www.woodsolutions.com.au/Articles/Resources/acoustic-guidelines and https://www.woodsolutions.com.au/Articles/Why-Wood/product-performance-acoustics.

Among many Technical Design Guides issued by Forest and Wood Products Australia, and downloadable at http://www.woodsolutions.com.au/Articles/Resources/Design-Construction-Guides, are two with an acoustic focus:
Guide 11 "Timber-framed Systems for External Noise"
Guide 2 "Timber-framed Construction for Multi-residential Buildings Class 2, 3 & 9 – design and construction guide for BCA compliant sound and fire-rated construction"

Manufacturer examples:

- **USG Boral – System+ complete manual** gives a full overview of all their systems, including acoustic specs for wall board and IT wall systems as well as design guidelines (pages A13-17 in the Dec 2015 edition). The complete manual is available at https://www.usgboral.com/content/dam/USGBoral/Australia/Documents/English/tech-guide/USGBoral_SYSTEMS+_complete_manual_Dec2015.pdf once registered on their site
- **GYBROCK – RED BOOK** http://www.gyprock.com.au/Pages/resources/red-book.aspx Advertises itself in Australia as "*The Gyprock RED BOOK is the most widely recognised and respected technical fire and acoustic wall and ceiling design guide in the plasterboard industry*." Section A has general theory, then later Sections are detailed solutions and materials for walls, floor, ceiling, junction, services, flanking path etc.

Other Australian based associations and professional bodies providing building acoustic information – as noted in the ABCB handbook [[60]] are:

- Association of Australasian Acoustic Consultants www.aaac.org.au
- Australian Acoustical Society www.acoustics.asn.au
- Australian Institute of Refrigeration, air conditioning and heating www.airah.org.au
- Australian Window Association www.awa.org.au
- Cement, Concrete and Aggregate Australia www.concrete.net.au
- Concrete and Masonry Association of Australia www.cmaa.com.au
- Associations of Wall and Ceiling Industries – Australian and NZ www.fwcianz.com
- National Timber Development Program www.timber.org.au
- Wood Solutions – www.woodsolutions.com.au. This site includes a range of technical design guides focussed on timber construction (https://www.woodsolutions.com.au/articles/technical-design-guides) , including several focussed on Acoustics such as [78]

E2.2.3 INTERNATIONAL EXAMPLES

Table giving some international design guide and regulation supporting documents:

Area	Design guide, manual, tool
UK	**Regulations Part E & Robust Details** *"The robustdetails® scheme is the alternative to pre-completion sound testing for satisfying Part E of the Building Regulations. Using the scheme avoids the uncertainties of pre-completion sound testing."* - http://www.robustdetails.com/ The Robust Details handbook is downloadable once registered on the site, and contains detailed construction advice for various combinations of building materials, and how they meet noise control requirements of the UK Building Code – Part E "Resistance to the passage of sound" https://www.gov.uk/government/publications/resistance-to-sound-approved-document-e or through the planning portal which also provides some useful information. https://www.planningportal.co.uk/info/200135/approved_documents See 6.3.1 for further discussion on the Robust Details system which is more than just the handbook of solutions.
ENGLAND	DEFRA - Department for Environment, Food and Rural Affairs - produces a **Noise Policy Statement for England** (March 2010) Ref: PB13750, setting out the aims of their noise regulations to provide context. https://www.gov.uk/government/publications/noise-policy-statement-for-england
UK	**NHBC (formerly the** National House Builders Registration Council (NHBRC)**:** *"NHBC is the UK's leading independent standard-setting body and provider of warranty and insurance for new homes, Our purpose is to work with the house-building industry to raise the standards of new homes and to provide protection for homebuyers in the form of Buildmark warranty and insurance."* - www.nhbc.co.uk. They carry out about 50% of the UK's new build inspections. Where Robust Details (above) can't be used they offer a variety of information on acoustic design http://www.nhbc.co.uk/productsandservices/consultancyandtesting/acousticservices/DesignAdvice/ including cases studies like these two on flanking sound transmission: http://www.nhbc.co.uk/Productsandservices/ConsultancyandTesting/Acousticservices/Documents/filedownload,44844,en.pdf http://www.nhbc.co.uk/ProductsandServices/ConsultancyandTesting/Acousticservices/documents/filedownload,45069,en.pdf

Area	Design guide, manual, tool
	Includes a useful brochure "Acoustics factsheet - Requirements for new homes" relevant to UK compliance: http://www.nhbc.co.uk/ProductsandServices/ConsultancyandTesting/Acousticservices/documents/filedownload,44449,en.pdf
Scotland	Scotland has some of the highest sound insulation regulations in Europe and is home to **Edinburgh Napier University,** home to the Building Performance Centre http://www.napier.ac.uk/research-and-innovation/research-search/centres/building-performance-centre which lead the development of the Robust Details system in England and has a very active involvement in building research www.gov.scot/Topics/Built-Environment/Building/Building-standards/publications/pubresearch/researchnoise Section 5 of the **Scottish building standards technical handbook** covers residential noise requirements for the Scotland beta.gov.scot/publications/building-standards-technical-handbook-2016-domestic/ – which provides clear background info on principles, full interpretations on the scope of the code, and compliance information including mandatory post completion testing requirements. **EXAMPLE Constructions and guidance** (over 100 construction detail guidance drawings) "Building Standards Division - EXAMPLE CONSTRUCTION AND GENERIC INTERNAL CONSTRUCTIONS FOR USE WITH

Area	Design guide, manual, tool
	SECTION 5: NOISE - OF THE TECHNICAL HANDBOOKS" http://www.gov.scot/Resource/0039/00393440.pdf" In 2012 Scotland launched **Robust Details in Scotland** with the RD Handbook currently being populated : www.robustdetails.com/other-services/robust-details-in-scotland and www.robustdetails.com/media/1254/section5_rd_handbook_may_2016.pdf Although not for new builds, the Scottish Building Standards Authority provides a >300 page online guide "**Housing and Sound Insulation – Improving existing attached dwellings and designing conversions**" by S.Smith, J.b.Wood, R. MacKenzie (http://www.gov.scot/resource/doc/217736/0099123.pdf) which includes a lot of useful information on sound insulation, general theory, stats on noise complaints (Scotland), options for improvement etc. Improving existing housing stock is another area worthy of consideration in the NZ context too – even if not strictly the focus of this study.
Canada	**NRC- National Research Council Canada** is the Government of Canada's premier organization for research and development and their building construction research includes a focus on multi-storey wooden construction – relevant for MDH. **SOUNDPATHS Software:** NRC also offer acoustic testing services and provide a useful online software called

Area	Design guide, manual, tool
	"SOUNDPATHS - A web application to predict the sound transmission between rooms" which with registration is intended for general construction industry usage. http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/soundpaths/index.html It is based on the Canadian Building Code and test data from products available in Canada but the idea could be transferrable. Results from the software can be used as part of compliance requirements in Canada. Supporting the Canadian Building Code (www.nrc-cnrc.gc.ca/eng/publications/codes_centre/2015_national_building_code.html) are Guide to calculating airborne sound transmission in buildings http://doi.org/10.4224/21268575 SoundPaths http://www.nrc-cnrc.gc.ca/soundpaths/soundPATHS_help.pdf Their code has recently changed to require calculation of flanking effects so they have developed these to help industry work to the new requirements
Ontario Canada	Canada Mortgage and Housing Corporation (CMHC) has been Canada's national housing agency for more than 65 years.and has produced a number of useful documents https://www.cmhc-schl.gc.ca/ . . A useful overview for Architects from 2005 was "Sound Control in Multi-family Wood-frame buildings". http://www.soundivide.com/uploads/content_file/multi-family_sound-control-en-277.pdf **, an** article which summarized information from the Best Practice Guide:

Area	Design guide, manual, tool
	Fire and Sound Control in Wood-Frame MultiFamily Buildings, published by Canada Mortgage and Housing Corporation (CMHC) 2002. Although no longer directly applicable it is a useful example of a guide aimed at Architects.
US	**The International Code Council** formed from 3 regional organisations in the US, produces the **International Building Code** which can be used as a model code for US States. The code is not freely available but they do provide a useful free resource – the ICC G2-2010 Guidelines to Acoustics available at http://media.iccsafe.org/store/2015Handbook/ICC_G2-2010.pdf which outlines requirements and offers context for usage and interpretation. **Engineered Wood Association** www.apawood.org *"The Engineered Wood Association is a nonprofit trade association that works with its members to create structural wood products of exceptional strength, versatility and reliability"* Includes public access (after free registration) to *"W460 Noise-Rated Systems: Fundamentals of acoustics, FHA recommendations and STC and IIC ratings for numerous panel construction assemblies. Revised August 2000"* https://www.apawood.org/noise-rated-systems-1 **along with other information on composite and laminate timber products**

Area	Design guide, manual, tool
European Commission COST action	COST (Cooperation in Science and Technology) is the longest-running European framework supporting trans-national cooperation among researchers, engineers and scholars across Europe. Various COST actions relate to acoustic design with handbooks of information available. See also Section 5.5.1 • COST Action TU0901 – Building acoustics throughout Europe. Volume 1: Towards a common framework in building acoustics throughout Europe http://vbn.aau.dk/files/207319005/TU0901e_bookVol1_TowardsCommFramewBuildAcouEurope_May2014_.pdf Volume 2: Housing and construction types country by country http://vbn.aau.dk/files/207464384/Volume_2.pdf • **COST Action TU 0702 - Net-Acoustics for Timber based Lightweight Buildings and Elements** **A copy of the related Ebook can be seen at** http://extranet.cstb.fr/sites/cost/ebook/EBOOK_%20Title+introduction.pdf **with** **"Chapter 4: Acoustic design of lightweight timber frame constructions" most relevant (also at** http://www.wtcb.be/homepage/download.cfm?dtype=research&doc=Acoustic_design_of_lightweight_timber_frame_constructions_PART_1.pdf&lang=en)

Area	Design guide, manual, tool
Austria/ Italy	**DataHolz** http://www.dataholz.com/en/index.html The Dataholz website is providing detailed design solutions for timber buildings appropriate for the Austrian building code. These include detailed specifications for materials for building elements and corresponding performance for a range of variations e.g. differing dimensions etc. Acoustic, thermal and fire performance are all included.
Italy	Consultancy/developers led informative brochure for acoustic design for timber structures (in Italian) see pages 22, 23 for design solution comparisons. https://tis.bz.it/it/it/cluster/legno-tecnica/doc/pdf/schallschutz_it Design guidelines by Rockwool (insulation) (in Italian) – see section 2.4 p.21-32 http://download.rockwool.it/media/101494/pubblicazione%20legno.pdf
Europe	**Prediction Software** • **Bastion** http://www.datakustik.com/en/products/bastian / "BASTIAN is the software to calculate airborne and impact sound transmission between rooms in buildings and airborne sound transmission from the exterior." Commercial software produced in Germany but used internationally, especially in Europe as the calculations in BASTIAN are based on parts 1 to 3 of the European Standard series

Area	Design guide, manual, tool
	EN 12354, being adopted by the majority of the European countries as part of their national standards. • **Son Architect** http://www.soundofnumbers.net/index.php/sonarchitect-iso *"SONarchitect ISO is the ultimate software for calculation of acoustic insulation according to EN 12354 parts 1,2,3,4 and 6 in entire buildings."* Includes prediction of sound insulation values for more complex combinations of building elements, as well as emission maps to outside. It is preloaded with European manufacturer information but can use import NZ data from the NZ based INSUL Software mentioned previously.
Austria	Acoustic information for (CLT) Cross Laminate Timber is only just becoming available as it is a reasonably new building material. Mass timber construction company KLH in Austria (www.klh.at) has produced many booklets including a guide with detailed solutions (incl floating floors, suspended ceilings, junctions etc) for multi storey residential CLT buildings, including their acoustic ratings (section 6 on) http://www.klh.at/en/download/public/Kreuzlagenholz/KLH_Residential_en.pdf KLH – Component Catalogue for Multi-Storey Residential Design 2012-

Area	Design guide, manual, tool
Chile	**Chile Acoustic design guidelines by the Chilean Ministry of Housing and Urbanism: Chile being on the pacific ring of fire needs to have good earthquake compliance for buildings. Although the following guide is in Spanish, there is a good range of explanatory images and the general approach is applicable to guidance for the construction industry.** http://www.minvu.cl/incjs/download.aspx?glb_cod_nodo=20070402125030&hdd_nom_archivo=manual_reglamentacion_acustica.pdf.
Singapore	The Singapore Building and Construction Authority produces a guide "**Code for environmental Sustainability of Buildings**" which sets out minimum environmental sustainability standards for buildings. It incorporates compliance requirements and details for a rating system (Green Mark score) for buildings including for internal noise as part of the internal environmental quality section. 3rd Edition Oct 2012 is available for download at https://www.bca.gov.sg/Envsuslegislation/others/Env_Sus_Code2013.pdf

E3 Academic Research

E3.1 INTRODUCTION

The research space in building acoustics (noise insulation) covers a range of disciplines, which in turn cover a range of building acoustics applications.

The disciplines range from the physical science aspects of theoretical, predictive methods and experimental measurements, to the subjective responses of the end users.

The building acoustics applications can be divided into:

- Direct airborne and impact sound transmission through the various intertenancy and external building elements (walls, floors, roofs, windows),
- Indirect sound transmission, where sound transmission paths through the building are more complicated (e.g. from a floor, under a wall, and then to a neighbouring floor).
- Building service noise, whether it be airborne or structure-borne noise. (e.g. air conditioning systems)
- Propagation of external noise around the building itself (e.g. screening of windows by balconies).

In this section a summary is provided of current global research which is either being done in the building acoustics space, or could be applied to building acoustics. This section is divided into the disciplines of predictive methods, experimentation, and subjective responses. To finish, lists and maps of currently active building acoustic research groups and testing facilities are provided.

Note www.ResearchGate.net is an invaluable tool for finding and accessing academic articles, getting in touch with authors or to follow current research projects.

E3.2 MODELLING AND PREDICTIVE METHODS

In this section various relevant modelling and predictive methods are briefly reviewed, with particular emphasis on applications in building acoustics. These are general methods of vibro-acoustics analysis, with the main focus often being automotive, aerospace and transport applications.

In summary, these include the following, with comments concerning applications to MDH and building acoustics.

- Finite Element Analysis (FEA): primarily suitable for detailed modelling of parts of a structure or within hybrid modelling approaches.
- Wave-based methods that describe the flow of energy from source, through the structure, to receiver.
- Wave and Finite Element (WFE) method: useful for prediction of wave properties and characteristics in complicated structures where analytical solutions are not available. Also useful for prediction of noise transmission and reflection/transmission properties.
- Wavenumber-space methods: semi-analytical approach for prediction of noise transmission.
- Periodic structure theory: efficient analysis of noise transmission through structures which comprise repetitive constructions (e.g. timber framed).

- Statistical Energy Analysis (SEA): describes the flow of energy through a structure.
- Hybrid VA1 method: combines FEA and SEA models of different parts of the same structure.

Note that many practical applications and future developments will involve a combination of more than one such method. Also it is worth emphasising that in MDH applications there is substantial uncertainty (i.e. lack of knowledge) about the *exact* material and physical properties of the structure and its components, and significant variability from one (sub)structure to another (i.e two different pieces of timber will have different elastic properties, and their values will not be known exactly).

Note references for this section (E3.2) are given in Section E3.2.4.

E3.2.1 OVERVIEW OF METHODS

E3.2.1.1 Finite Element Analysis (FEA)

FEA has become a widely used tool in engineering (Zienkiewic and Taylor, 2005; Petyt, M. 1990 and 2010). Many commercial packages are available, although the cost is significant. The FE model can capture the *full detail* of a structure or a structural component, its geometry and its material properties. This makes it unsuitable for modelling a complete building: the size of the model is too large and the computational cost prohibitive. However, it is valuable for modelling components and small regions, normally in conjunction with other methods (e.g. WFE method, Hybrid method).

Various methods have been developed for model reduction: trying to reduce the computational cost. These include component mode synthesis (CMS) (Craig, 1981, Craig, 1995), characteristic constraint (CC) modes (Castanier *et al*, 2001) and automated multilevel sub-structuring (AMLS) (Benninghof *et al* 2000, Benninghof and Lehoucq 2004, see also http://www.cs.sandia.gov/~rblehou/amls-rev.pdf). Other approaches (e.g. Krylov methods (Bai 2002)) instead aim to reduce the cost of multiple solutions to the problem by rephrasing in terms of the solution at one frequency.

Given the typically complexity, it is not felt that FEA is a viable approach to the modeling of complete buildings, but instead has an important role in hybrid approaches, where it is used to fully model the detail of components or small regions of the structure.

E3.2.1.2 Element-based methods for acoustic spaces

Various further methods have been developed for acoustic spaces. For unbounded problems (i.e. radiation away from vibrating surfaces) infinite elements (Astley et al 1998) attempt to model the region extending away from the structure to infinity while Perfectly Matched Layers (PMLs) (e.g. Zampolli, et al, 2007)) wrap a non-reflecting layer around the structure.

More relevant in the current context is the boundary element method (BEM), a well-established technique that relates pressure in the air to the vibrations of the surfaces surrounding it (Fahy and Walker 2004). This results in a smaller model, but one which is nonetheless computationally costly. Recent work appears to be concentrated on making the solution algorithms faster and more efficient, e.g. the fast multipole method (FMM).

In summary, these methods are likely to be prohibitively costly, except perhaps as part of hybrid schemes.

E3.2.1.3 Wave based approaches

Wave approaches are appealing for building acoustics problems. They describe the behaviour in terms of structure-borne and airborne waves which propagate from the source, through the air and structure to the receiver, being transmitted and reflected at boundaries, joints etc. Examples include both steady-state and transient problems. Knowledge of the dispersion relations, group velocity, reflection and transmission characteristics etc., enables predictions to be made of disturbance propagation, energy transport and so on. These are also valuable for the prediction of other quantities, such as modal density and coupling loss factors in SEA (Lyon and Dejong, 1995, but see below).

In simple cases, analytical expressions for the dispersion equation can be found (Graff, 1975, Cremer et al, 2005). For more complex constructions, at higher frequencies, or when the thickness is comparable to the wavelength, the analysis becomes difficult and a numerical approach is very desirable, such as the WFE method (below). One further issue concerns the estimation of reflection and transmission coefficient of joints or junctions between two or more components. These describe the flow of energy from one component to another and, when averaged for a diffuse incident field, are used to estimate transmission loss and coupling loss factors. For simple geometries and components analytical solutions are straightforward (Graff, 1975, Lyon and Dejong, 1995, Cremer et al, 2005). For more complicated joints a numerical approach is necessary.

E3.2.1.4 Wave and Finite Element (WFE) method

The wave and finite element (WFE) method (Mace et al, 2005, Mace and Manconi, 2008) is a hybrid method that uses a finite element model of a small segment of a structure to predict wave properties. The cross-section of the structure can be complicated, so that it is well-suited to the analysis of walls or panels of arbitrary complexity through the thickness. Conventional FEA methods are used, with their outputs being post-processed using periodic structure theory. Computational cost is small.

The WFE method has been applied to free and forced response of tyres, two-dimensional homogeneous solids, laminates, foam-cored panels, extruded panels, constrained layer damping treatments, axisymmetric structures such as laminated and foam-cored shells and fluid-filled cylinders. It has also been used to calculate wave transmission through joints. For joints of complicated construction a hybrid FE/WFE approach (Renno and Mace, 2011), models the joint using conventional FE and the beams using WFE.

It has recently been extended to predict noise transmission through infinite panels (Yang *et al* 2016), with research on finite panels and periodically stiffened panels in progress.

E3.2.1.5 Wavenumber-space methods

The response of a structure can be found by decomposing it into a series of time and space harmonics. This is in principle achieved by Fourier Transforms. For such excitation the differential equations of motion become algebraic equations in frequency and wavenumbers, which are relatively easy to solve. The response to more general excitation, including transients, is then found by inverse transforms, typically by evaluating inverse FFTs.

Such approaches – through solving in the wavenumber domain – have been applied to many problems, and lies behind the application of wave methods generally, including WFE. It has been applied to modelling noise transmission through aircraft structures (Heron and Nash, Qinetiq, personal communication) and laminated cylinders characteristic of aircraft structures (Heron, 2002), together with applications in building acoustics, as described below.

E3.2.1.6 Periodic structures

A periodic structure is one that is built-up from a series of identical cells which repeat periodically in space. Examples include stiffened timber-framed structures and plate structures such as those often encountered in aircraft and marine applications.

The analysis of the whole structure involves the analysis of a single periodic cell and the application of periodic structure theory. Early works by Mead and co-workers (Mead, 1975a,b, Mead and Parthan, 1979) were aimed partly at noise and vibration modelling and reduction in aircraft. FE can also be employed to analyse the dynamics of the periodic cell (Orris and Petyt, 1974, Abdel-Rahman, 1979). More recently these FE-based approaches have been used as the basis for the WFE method and to estimate SEA parameters for periodic subsystems (Cotoni et al, 2008), together with WFE-based methods for the prediction of noise transmission.

Of particular interest in building acoustics is the transmission of sound through such stiffened structures. Early works concerned periodically stiffened plates (Mace 1980) and cross-stiffened plates (Mace 1981). The approach has subsequently been extended by various authors, notably Brunskog (2005a, 2005b), who has considered representative structures comprising timber framing (Brunskog 2005a) including cavities (Brunskog 2005b), double-plate constructions (Brunskog and Davidson 2004), impact transmission on floors (Brunskog and Hammer 2000, 2003) and flanking transmission (Brunskog *et al* 2007).

E3.2.1.7 Statistical Energy Analysis (SEA) and energy methods

Energy models give a “broad-brush” description of the dynamic behaviour of a structure. The system is divided into a (relatively small) number of coupled subsystems and the response to excitation (often assumed to be random, broadband and stationary) described in terms of the time and frequency average energy in each subsystem, the energy flows between them and the input powers. Statistical Energy Analysis (SEA) (Lyon and Dejong, 1995, Crichton *et al* 1992) is the most well-established energy-based method and gives a prediction of the average response in various parts of the structure (mean-square sound pressure level in air spaces, mean-square velocity in walls, floors etc). It is a valuable approach at higher frequencies: the computational cost is typically small, but detail regarding the frequency and spatial variation of the response is lost.

It has widespread use in automotive and aerospace industries, especially above 1500Hz or so, together with application in building structures (Craik 1996), including timber-framed structures (Craik *et al* 2005). It has a somewhat mixed reputation in New Zealand, partly because it is somewhat more demanding on the analyst, perhaps, and partly because there are limitations on its accuracy: these become most noticeable at low frequencies (a few hundred Hz or so), in structures such as framed walls (which have a noticeably non-uniform modal distribution) and where there is a significant directional acoustic field (e.g. corridors).

Application of SEA requires knowledge of various parameters, including loss factors (normally empirical) and coupling loss factors (CLFs). Theoretical expressions exist for these CLFs for some circumstances, commonly using a wave approach (Lyon and Dejong, 1995, Crichton *et al* 1992, Norton, 1989). Numerical estimates of the CLFs can be obtained from FEA of *parts* of the whole system using a method referred to as Energy Distribution Analysis (EDA) (Mace and Shorter, 2000) and for complicated constructions the WFE method can be used to estimate the CLFs. The “Virtual SEA” approach (Gagliardini et al, 2005) is a numerical implementation of the EDA method that also attempts to identify an appropriate substructuring scheme based on the division of the structure into regions of more-or-less equal energy, reducing the level of expertise required by the engineer applying SEA. Finally periodic substructures can be included in SEA models using the method described by Cotoni *et al*.

SEA has become well established and is widely used for high frequency noise and vibration modelling and design in automotive, aerospace, marine and building industries. Commercial software packages are available (AutoSEA, SEAM, VA1). These provide convenient user interfaces and databases of CLFs, material properties etc. SEA requires some user experience and judgement. Techniques are available for the development of experimental SEA models (Bies and Hamid, 1980). SEA predicts the mean response, and expressions for the variance of the response have also been developed (Langley and Cotoni, 2004).

Various other energy-based methods have been proposed, but have not had wide take-up. They include conductivity approaches (O. M. Bouthier and R. J. Bernhardt 1992, Lebot, 2002), appropriate to highly damped components, and Wave Intensity Analysis (Langley, 1992), which attempts to capture more detail than conventional SEA by removing the assumption of a diffuse wavefield in each subsystem.

Dynamical energy analysis (DEA) (Tanner, 2009) is a new approach towards determining the distribution of mechanical and acoustic wave energy in complex built-up structures. The method lies somewhere between SEA and full ray tracing, retaining some degree of phase information in the wave description. The technique has been extended to include hybrid models, where some subsystems are modelled by FEA and some by DEA/SEA (Maksimov and Tanner, 2011). The method has been commercialised by inuTech (https://inutech.de/).

E3.2.1.8 Hybrid "VA1" method

A hybrid FE-SEA method has been developed in recent years (Shorter and Langley 2005a, 2005b, Shorter *et al* 2004). It is coded in the commercial software "VA1" (https://www.esi-group.com/software-solutions/virtual-performance/va-one-vibroacoustics-simulation-software). It is a hybrid approach which couples FE models of small regions of the structure to "high mode count" components which are best modelled by SEA. It thus merges the two approaches, and is suitable for applications where the detail of an FE model is needed for some parts (e.g. connectors) while an SEA description is ideal for others: these are described by the superposition of direct and reverberant wavefields, which are coupled to the FE regions of the structure in a systematic manner through a dynamic stiffness matrix formulation. The method has been applied to industrial examples, particularly in the automotive, rail and aerospace industries.

E3.2.2 COMMERCIAL SOFTWARE

This list is by no means exhaustive, but commercially available packages include the following:

- FEA: ANSYS, ABAQUS, Nastran, LMS Virtual.Lab, ANSOL, Comsol etc
- BEM: LMS Virtual.Lab, SysNoise, ANSOL.
- SEA: AutoSEA, SEAM, VA1, LMS Virtual.Lab, ASEA and VSEA (InterAC)
- DEA: Diffpack DEA
- Hybrid method: VA1

E3.2.3 OPTIMISATION

Optimisation of building constructions involves design of individual components and the overall system with respect to various performance considerations: maximisation of transmission loss, minimisation of flanking transmission etc., in the presence of constraints regarding structural, thermal, fire, cost and other considerations. While some work has been done concerning optimisation of acoustic performance, there are many open questions and problems, and scope for significant improvements.

Successful optimisation requires effective modelling methods. Often these involve hybrid approaches: finite element models of small parts of the structure to capture detail in geometry, material properties etc., with wave or SEA models of the remainder of the structure, air spaces etc. Methods include the WFE approach and the hybrid method, with Reynders et al. (2014) applying the latter approach to the prediction of sound transmission in walls. Potentially, multi-scale approaches might be required to capture detail and small length scales. Such investigations would also allow for new materials and designs to be considered. Optimal solutions need also to be robust (i.e. insensitive to inevitable small variation on the properties of the system).

In lightweight double-leaf walls it is well known that stud geometry has a significant effect on noise transmission (Hongisto et al (2002)). Steel studs in particular offer much freedom in the design of the detailed geometry, the cross-sectional shape, the inclusion of longitudinal slits etc. together with the incorporation of damping treatments, laminations etc., and potentially even resonant attachments.

Perforation topology has a significant influence on sound insulation of hollow lightweight masonry walls (Jacques et al. (2011), Fringuellino and Smith (1999)).

In the automotive industry FEA has been used to optimise the shape and stiffening of panels given constraints on noise, vibration, mass and stiffness (Marburg (2002)). The size of such FE models is of course very small compared to what would be required for MDH applications, hence hybrid methods are required.

Topology optimisation for acoustic performance has been considered in a number of applications: the (2-dimensional) shape of a noise barrier (Dühring et al (2008)); the material distribution in a sound insulating panel (Yamamoto et al. (2009)); the shape of the cellular cores in a sandwich structure for maximum sound insulation (Denli and Sun (2007)); the design of a sandwich panel (Cameron et al. (2014)) and a stiffened panel (Joshi et al (2015)). Phononic materials, with band-gaps tuned to attenuate structural wave propagation in prescribed frequency bands, are another example (see e.g. Bilal and Hussein (2011) and section 5.3).

E3.2.4 SECTION E3.2 REFERENCES

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E3.3 BUILDING ELEMENTS AND STRUCTURES

This section identifies recent studies which have investigated the acoustical performance of building structures or elements which might be typical in future medium density houses in New Zealand. It begins with a review of recent work on the development of prediction methods and concludes with a review of several potential novel systems and materials which may be incorporated into such structures.

Note references for this section (E3.3) are given in Section E3.3.3

E3.3.1 RECENT DEVELOPMENT OF PREDICTION METHODS FOR LIGHTWEIGHT BUILDING STRUCTURES

Ideally, new building structures could be evaluated prior to construction using purely theoretical models. However, New Zealand buildings often make use of lightweight structures, e.g. timber frames and walls constructed of plasterboard mounted on metal studs, for which existing standardised methods for predicting the acoustic performance can be somewhat unreliable [1], [2].

For example, the method described in EN 12354 [3, 4] for predicting flanking noise transmission has been shown by numerous recent investigations [5,6,7,8] to be inappropriate for lightweight building constructions. A number of more advanced methods for predicting sound transmission in lightweight structures are available or are currently being developed.

[9] has proposed a modified prediction method for assessing the acoustic performance of lightweight structures based on EN12354 [3,4]. However, as is common with SEA approaches, the method relies on the experimental measurement of quantities such as the sound reduction index of wall elements and the vibration reduction index at junctions between elements. Procedures for measuring these quantities are described in [10].

Hybrid FEM/SEA models for predicting the acoustic performance of timber buildings are also being developed as part of the European Silent Timber Build project [11]. Descriptions and validation of these methods can be found in [9], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21] and [22].

E3.3.2 NOVEL SYSTEMS AND MATERIALS

A large number of recent experimental studies have been undertaken to investigate the acoustic performance of lightweight timber-framed building constructions which are gaining popularity as materials for use in medium density housing in Europe.

Of particular interest is the performance of Cross-Laminated Timber (CLT) which is a prefabricated solid engineered wood product made of a minimum of three orthogonal layers of lumber boards which are bonded and pressed to form a solid panel.

CLT may be used as structural components in both wall and flooring systems. In particular, a significant portion of the research effort on the Silent Timber Build project [11] appears to have been spent assessing the acoustic performance of CLT systems and developing models for predicting their acoustic performance. The acoustic performance of CLT, and in particular impact insulation performance, appears to be relatively poor in comparison to conventional European building construction systems.

At the recent International Congress on Acoustics, a special session was held entitled "Calculation models for timber structures (Silent Timber Build)" in which members of the project presented their work. Many of these papers investigated the performance of CLT structures. [23] presents a range of acoustic data which is used for validation of the models described in the previous section and [7] and [24] both investigated the impact insulation performance of a range of different hybrid CLT structures by analysing a range of laboratory measurements.

A number of independent studies have also been undertaken to investigate the acoustic performance of CLT systems. These include [8] who describes a study in which the impact and airborne sound insulation performance of CLT wall systems are assessed via laboratory and in-situ measurements. Also, [6] describes an experimental investigation undertaken using a two-storey experimental facility made entirely from CLT which was used to characterise the vibration attenuation in various junction types, some of which included resilient materials to reduce flanking transmission.

Finally, [25] describes an experimental study on the acoustical insulation provided by 14 different CLT wall systems. It was found that airborne sound insulation could be improved by fixing various systems to one or both sides of the CLT member e.g. mounting plasterboard off the CLT element using resilient mounts, inserting sound absorbing material between the plasterboard and CLT element and/or applying a mortar or resin to the surface of the CLT element.

In addition to CLT, other lightweight systems are being investigated. For example, the acoustical performance of a hybrid timber concrete floor was assessed in [26] using an SEA method and experimental measurements. The method was shown to be very reliable – but requires the experimental measurement of various structural parameters as input.

[27] describes an experimental study investigating the impact sound insulation properties of various lightweight timber platform floating floors on a concrete floor base. The study investigated using open cell foams as resilient materials beneath the floating floors.

[28] describes an empirical model for calculating the direct sound transmission through lightweight wood-framed constructions. The model was based on transmission loss measurements undertaken in the National Research Council (NRC) of Canada wall sound transmission facility. Each of the walls consisted of 90mm wood studs with glass fibre cavity insulation and made use of resilient channels. Four parameters were varied namely: Gypsum board layers and thickness, stud spacing and resilient channel spacing.

Damping is widely used to control noise and vibration. In structures, (normally thin) layers of viscoelastic material can be applied to metal sheet to add damping. These layers can be unconstrained or constrained [29]: in the latter case an additional (thin) metal layer is applied to the outer surface to enhance shear in the viscoelastic layer, substantially increasing damping. With proper design [30], damping can be optimised with regard to host structure thickness and stiffness, frequency, temperature, cost and so on. A very wide range of products is available. Damping layers are used in other, non-metallic products. One example is glazing: automotive windshields are laminates with often 5 layers of glass and viscoelastic material. Such damping layers could be incorporated in materials such as CLT to enhance damping, but appropriate design would be required to optimise performance.

Metamaterials are materials whose properties exceed those of the individual materials from which they are constructed [31]. Examples include fibre-reinforced composites, laminates and constrained layer damping treatments.

Periodic structures are another form of metamaterial. These are structures which are spatially periodic, often through there being periodically spaced attachments such as stiffeners or resonators. Periodic structures have unusual wave-bearing characteristics. There are pass and stop bands, frequency bands in which waves can propagate freely or attenuate, respectively. These effects are due to Bragg scattering, and this raises possibility for control. However, the size of the structure must be large compared to the wavelength for these effects to become evident and, while there are applications in phononic crystals, fibre optics, MEMS devices and so on, applications in building acoustics are unlikely.

More appealing perhaps is the use of resonant attachments to control wave (air-borne or structure-borne) propagation. These act in the same way as vibration absorbers. They can be tuned to a particular frequency to control motion in an often-narrow frequency band. The concept has attracted substantial interest in recent years, with [31] providing a detailed review.

Such resonant devices have potential to control sound transmission, but the ability to control impact noise, over a broad frequency band or a diffuse incident field is a moot point. Resonators, if appropriately tuned and designed, can significantly enhance damping and can be embedded in structural components (e.g. CLT) or attached to panels.

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E3.4 SUBJECTIVE ANALYSIS OF BUILDING ACOUSTICS

E3.4.1 INTRODUCTION

Objective measurements and the resulting measures and metrics are used to describe the sound insulation performance of building systems. E.g. the airborne sound insulation of a building element is measured in third octave bands, and in accordance to ISO 717, Rw gives a measure of the overall performance. These objective metrics often have been developed from people's subjective responses to sound insulation. These subjective responses are usually determined either through surveys asking people how they feel about the sound insulation in their apartment, or by way of presenting people with pre-recorded sounds in simulated environments and asking them to ranks such sounds.

There is an on-going effort to test current sound insulation and noise metrics, and to see if other metrics may be more suitable. This section is a summary of recent (last 5 year) research into these subjective-based metrics.

In summary, the main emphasis is on whether current metrics are suitable for the newer, lightweight construction systems, and whether it is important to consider very low frequency sounds (below 100Hz) in the sound insulation metric. There is also work to see whether different sound sources should be used to better reflect real-life experiences.

References for this section can be found in Appendix A - References

E3.4.2 RELEVANCE OF RATING SYSTEMS

In 2011 the Europeans announced that they would be reassessing the building acoustic ratings found in ISO 717 (which are cited in the proposed update to the New Zealand Building Code Clause G6 [24]), taking the opportunity to simplify it, and to incorporate the results of new subjective research.[79]

A recent Swedish project, AkuLite [80], was instigated to find out to what extent objective measured parameters correlate with subjective opinions from people living in multifamily houses. Since the emergence of lightweight building systems during the last few decades, the question of whether standardized sound insulation evaluation methods are still appropriate has been often raised. They found that statistical analyses between the measured parameters and the subjective ratings revealed a useful correlation between the rated airborne sound insulation and R'w +C50-3150 while the correlation between the rated impact sound insulation and Ln,w'+CI, 50-2500 was weak.

Research has been done in Europe to produce ISO single figure sound rating systems which are more reflective of subjective ratings[81], this includes comparing lightweight with heavy construction, by looking at low-frequency responses[82]. There has also been work on how to standardize rating systems across Europe via Cost action TU0901 [83-85].

Research has also looked at whether somewhat different ratings systems can be more correlated with subjective assessment of sound insulation, such as loudness[86, 87] or time-dependant features[88].

Some work has also looked at how other factors come into play when considering the subjective response to sound insulation, e.g. some personalities are more susceptible to noise[89], and the current situation of the subject will affect outcomes[90]

E3.4.3 FLOOR IMPACT NOISE

There has been a lot of work looking at impact sounds on lightweight floors compared to heavy floors. The focus has often been on footstep or other low-frequency type sounds, and how one can simulate or otherwise replicate these sounds in measurements[91, 92]. Some work has looked at whether the ability to localise the source of the sounds is important [93]. The recent 'AkuLite' project suggested that impact sound is better correlated with subjective response when frequencies down to 20Hz are incorporated [94, 95].

Korean work on subjective response of impact noise focuses on heavy, low-frequency impact sounds such as jumping on the floor, producing equivalent objective measurements and rating schemes [96, 97]. Usually they only concern themselves with massive concrete construction. The Japanese have extended the so-called heavyweight impacts to wooden, lightweight floors[98], finding that higher frequencies are more important than the very low frequencies. They also found that a Loudness rating (Zwicker model) was best correlated with subjective impressions of annoyance[99, 100].

Work in New Zealand on subjective response of impact sounds on light and medium weight floors also showed that a loudness measure of suitable impact sounds (such as footsteps and heavy ball drops)[101]. This subjective work was done using sound comparisons in a listening room at the University of Auckland.

E3.4.4 AIRBORNE SOUND INSULATION

Work has looked at whether the ISO rating systems' spectrum adaptation terms in ISO 717 should be extended to include other source spectra (such as aircraft noise)[102]. Recent subjective comparison of airborne sound insulation in lightweight versus massive walls suggest that when Rw =55dB construction type doesn't matter and R'w is better related to subjective results than R'w +C50-3150[103]. Other subjective work on lightweight and massive walls has also determine that subjective results are not so correlated with low-frequency response[104]

E3.4.5 EXTERIOR NOISE

Direct subjective surveys have been carried our recently. In the Norwegian facade insulation study [105, 106], the efficacy of facade insulation in providing an improved indoor noise environment and in reducing indoor noise annoyance was examined in a socio-acoustic before-and-after study with a control group.

E3.4.6 EFFECT OF BACKGROUND NOISE

Some studies have also considered what role background noise plays in reducing the need for large degrees of sound insulation[107]

E3.4.7 RELEVANT PROJECTS

AkuLite : Correlation between measured vibro- acoustic parameters and subjective perception in lightweight buildings (Sweden - 2013). [80]

The **Norwegian facade insulation study** [105]: the efficacy of facade insulation in providing an improved indoor noise environment and in reducing indoor noise annoyance was examined in a socio-acoustic before-and-after study with a control group

European project COST Action TU0901: Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions (2013) [12]

European project COST Action FP0702: Net-Acoustics for Timber based lightweight buildings and elements (2008-2012), Working Group 3: Comfort assessment for sound and vibration [108]

E3.5 SURVEY OF TEST FACILITIES AND RESEARCH GROUPS

This section includes some major research activities in the European Union (EU), along with maps and lists of test facilities and research groups worldwide with a focus on building acoustics.

E3.5.1 EUROPEAN UNION (EU) ACTIVITIES

Various relevant activities in EU are summarised here, with further details below and in the references.

E3.5.1.1 Overview

Silent Timber Build (http://silent-timber-build.com/) A consortium of mostly industrial participants concerning multi storey timber buildings. The aims included

- Developing accurate prediction tools (based on EDA/Virtual SEA).
- Applying and disseminating knowledge.
- Describing competitive and efficient solutions.
- Increasing and disseminating knowledge about the prediction models and efficient solutions among the industry and consultants

HCLTP (http://www.hcltp.com/) Hybrid Cross Laminated Timber Plates concerns the development of new types of hybrid cross laminated timber plates, namely plates combined with timber ribs or a concrete topping. Modelling approaches involve FEA. A small consortium of 7 partners.

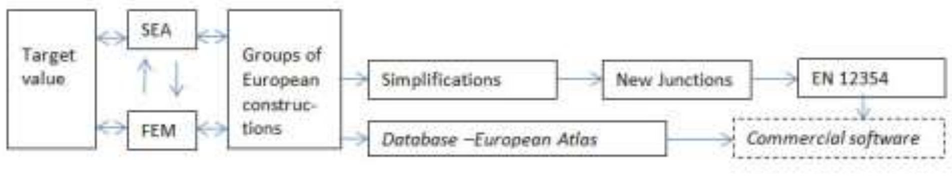
AcouBois project of the French wood industry

(http://www.codifab.fr/actions-collectives/bois/article/acoubois-performance-acoustique-des-constructions-ossature-bois)

AcouBois project, 2009 - 2014 dealt with (1) making an acoustic database of French typical walls and floors, measured in an acoustic facility. (2) Adapt a calculation method for flanking transmissions. (3) Validate the process using in-situ measurements.

COST actions

There have been and are a number of relevant COST Actions. Further details are given below, but in summary they include the following.



Schematic and simplified overview of the project idea

- COST Action TU0901 (Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions, http://www.costtu0901.eu/) 2009-2013.
- COST Action FP0702 ("Net Acoustics", http://extranet.cstb.fr/sites/cost/default.aspx: Net-Acoustics for Timber based lightweight buildings and elements) 2008-2012.
- COST Action CA15125 ("DENORMS", https://denorms.eu/ : Designs for Noise Reducing Materials and Structures) 2016 – 2020.

FP7 and Horizon 2020

Various other projects have been funded, with the emphasis being on general methods and applications to transport in particular. They include:

- Mid-frequency "CAE Methodologies for Mid-Frequency Analysis in Vibration and Acoustics" (http://www.midfrequency.org/). (MCITN)

- Mid-Mod "Mid-frequency vibro-acoustic modelling tools – Innovative CAE methodologies to strengthen European competitiveness." (http://www.mid-mod.eu/). FP7 cooperation project.
- MIDEA "Mid-frequency energy analysis" (http://www.inutech.de/midea/). IAPP concerning the DEA method.
- Superpanels IRSES project, concerned with the vibroacoustics behaviour of panels, laminates etc.

E3.5.1.2 Silent Timber Build

Silent Timber Build (http://silent-timber-build.com/): A consortium of mostly industrial participants concerning multi storey timber buildings. The aims included

- Developing accurate prediction tools (based on EDA/Virtual SEA).
- Applying and disseminating knowledge.
- Describing competitive and efficient solutions.
- Increasing and disseminating knowledge about the prediction models and efficient solutions among the industry and consultants

Predictive tools were centred around the hybrid SEA/FEA approach (EDA/Virtual SEA). The overall relationships between the various elements of the programme are illustrated in this block diagram.

Participants:

- SP Technical Research Institute of Sweden
- Lund University, Sweden
- TU Graz, Austria
- CSTB, France
- FCBA, France
- InterAC, France
- Fraunhofer, Germany
- Sintef, Norway
- Lignum, Switzerland
- CES-Bois, Belgium
- WSP, Sweden
- Fristad Bygg, Sweden
- Norgeshaus, Norway
- Bauer Holzbau, Germany
- Tecnalia, Spain

E3.5.1.3 HCLTP – Hybrid Cross Laminated Timber Plates

HCLTP - Hybrid Cross Laminated Timber Plates, http://www.hcltp.com/

Hybrid Cross Laminated Timber Plates is a *Wood Wisdom Net* research and development project funded by the European Commission and national authorities of project partner countries. It concerns the development of new types of hybrid cross laminated timber plates, namely plates combined with timber ribs or a concrete topping. Modelling approaches involve FEA.

Wood Wisdom Net (http://www.woodwisdom.net/) commenced under FP7 funding, then continued under ERA-NET Plus scheme, and concerns the timber industry in general.

Partners:

- University of Ljubliana, Slovenia
- CBD, Slovenia
- MPA, University of Stuttgart, Germany
- Stora Enso
- Ledinek, Finland

- ITI, Vienna University of Technology, Austria
- Joze Cernivsek, Slovenia

E3.5.1.4 COST Actions

COST Action TU0901 (Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions, http://www.costtu0901.eu/) 2009-2013.

The main objective of the Action was to harmonise the descriptors for airborne and impact sound insulation between dwellings and for airborne sound insulation of facades as well as to prepare a European classification scheme with a number of quality classes. The Action produced 2 E-books (http://www.costtu0901.eu/tu0901-e-books.html):

- Building acoustics throughout Europe Volume 1: Towards a common framework in building acoustics throughout Europe
- Building acoustics throughout Europe Volume 2: Housing and construction types country by country

Links are given to various other relevant projects in EU (http://www.costtu0901.eu/tu0901-e-books/additional-info/COST%20TU%200901%20based%20Projects.pdf/at_download/file).

There were approximately 80 participating partners from 26 different countries (AT, BE, HR, DK, EE, FI, MK, FR, DE, GR, HU, IS, IT, LT, NL, NO, PL, PT, RO, RS, SK, SI, ES, SE, CH, UK). The Action Chair was Birgit Rasmussen, DK, bir@sbi.dk

COST Action FP0702 (“Net Acoustics”, http://extranet.cstb.fr/sites/cost/default.aspx: Net-Acoustics for Timber based lightweight buildings and elements) 2008-2012.

This action focused on the acoustics and low frequency vibration of timber based lightweight buildings and building elements. Airborne and impact sound performances as well as sound from service equipment were considered over a frequency range including low frequencies (50 to 100 Hz) where lightweight buildings are likely to have performances lower than in heavy buildings. Low frequency vibration (below 25 Hz) such as floor vibration due to people walking was also considered. An E-book with 5 chapters was produced (http://extranet.cstb.fr/sites/cost/ebook/Forms/AllItems.aspx):

- Chapter1: Prediction methods for sound and vibration performances
- Chapter2: Measurement methods for sound and vibration performances
- Chapter3: Comfort assessment for sound and vibration
- Chapter4: Building acoustics design
- Chapter5: Overview of research at the main member institutes

15 European countries (AT, AU, BE, CH, DE, DK, ES, FR, GB, IE, LT, NL, NO, NZ, SE, SI, UK) as well as Australia (RMIT and CSIRO) and New Zealand (University of Canterbury). Participating institutions included

- Lulea University of Technology, Sweden
- Liverpool University, UK
- CSTB, France
- Hochschule Rosenheim, Germany
- PTB, Germany

- Holzforschung, Austria (HFA) with Technical University, Vienna, Austria
- TECNALIA Spain
- BBRI, Belgium
- SINTEF, Norway
- University of Canterbury, Christchurch New Zealand
- RMIT and CSIRO, Australia
- NTNU, Trondheim, Norway
- FCBA, France
- Center for Timber Engineering, Edinburgh Napier University, Scotland

COST Action CA15125 ("DENORMS", https://denorms.eu/ : Designs for Noise Reducing Materials and Structures) 2016 – 2020.

Recently started, DENORMS aims at designing multifunctional, light and compact noise reducing treatments, including acoustic metamaterials, sonic crystals and conventional acoustic materials. New approaches to the theory of sound interaction with materials and structures and standard methods of their performance characterisation are being developed. Participants include:

Austria

TGM – Die Schule der Technik

Belgium

Huntsman Europe bvba
University of Leuven (KUL) – PMA division and Department of Physics
Siemens Industry Software NV

Croatia

University of Zagreb – Faculty of Electrical Engineering and Computing (FER)

Czech Republic

Czech Technical University in Prague (CTU)
Technical University of Liberec (TUL)

Denmark

Technical University of Denmark (DTU)

Estonia

Tallinn University of Technology (TUT) – Department of Machinery

Finland

University of Eastern Finland (UEF)

France

Aircelle – Safran
Centre de Transfert de Technologie du Mans (CTTM)
CERA Acoustic Products & Systems
DCNS Research – Department of Acoustics
Ecole Nationale des Travaux Publics de l'Etat (LGCB – ENTPE) – Université de Lyon, UMR CNRS 5513
Institut d'Électronique, de Microélectronique et de Nanotechnologie (IEMN) – CNRS
Institut National des Sciences Appliquées (INSA) – GREMAN (UMR 7347)
Institut Supérieur de l'Automobile et des Transports (ISAT) – Université de Bourgogne
Institut supérieur d'électronique et du numérique (ISEN)
Institut Supérieur de Mécanique de Paris (Supméca)
Laboratoire d'Acoustique de l'Université du Maine (LAUM) – CNRS UMR 6613

Laboratoire de Mécanique et d'Acoustique (LMA) – CNRS UPR7051
Laboratoire Modélisation et Simulation Multi Echelle (MSME) – Université Paris-Est Marne-la-Vallée, UMR CNRS 8208
Matelys – Acoustique & Vibrations
Met@coustic
Saint Gobain – ISOVER
SNECMA – Safran
Université de Technologie de Compiègne (UTC)

FYR Macedonia

SS. Cyril and Methodius University (UKIM) – Faculty of Civil Engineering

Greece

Foundation for Research and Technology (FORTH)
National Technical University of Athens (NTUA) – School of Mechanical Engineering
Technological Educational Institute of Athens (ITEIATH) – Department of Energy Technology Engineering

Ireland

Trinity College Dublin (TCD)

Israel

Shenkar College of Engineering and Design
Technion Faculty of Aerospace Engineering

Italy

Università degli Studi di Ferrara (Unife) – Engineering Department
Università degli Studi di Roma Tre

Lithuania

Kaunas University of Technology (KTU) – Laboratory of Institute of Architecture and Construction
Vilnius Gediminas Technical University (VGTU) – Institute of Environmental Protection

Poland

Polish Academy of Sciences (PAN) – Institute of Fundamental Technological Research Warsaw University of Life Sciences (WULS) – Faculty of Civil and Environmental Engineering

Portugal

Embraer R&D Portugal Office

Romania

National Institute for Laser Plasma and Radiation Physics (INFLPR)
SC AIRAM AUM SRL
SC CRV Profesional SRL
SC Green Acoustics SRL
Universitatea Politehnica din Bucuresti (UPB) – Departamentul de Mecatronica si Mecanica de Precizie

Serbia

University of Nis – Faculty of Electronic Engineering
University of Novi Grad (UNS)

Slovakia

Slovak University of Technology in Bratislava (STUB)

Slovenia

University of Ljubljana – Biotechnical Faculty
University of Ljubljana – Faculty of Mechanical Engineering
University of Ljubljana – Faculty of Natural Sciences and Engineering

Spain

Universidad de Cantabria (UNICAN)

Universitat Politécnica de Valencia (UPV)
Universitat Politécnica de Valencia (UPV – EPSG) – Escuela Politécnica Superior de Gandia

Sweden

Chalmers University of Technology – Civil and Environmental Engineering
KTH Royal Institute of Technology (KTH) – Aeronautical and Vehicle Engineering

The Netherlands

NOVIC Noise and Vibration Control
Eindhoven University of Technology

UK

Carbon Air Ltd.
Defence Science and Technology Laboratory (DSTL)
Dyson Ltd
The Open University (OPU)
University of Birmingham (UB)
University of Exeter
University of Salford
University of Sheffield

United States

Massachusetts Institute of Technology (MIT)
Rutgers University
University of Arizona
University of Washington

The University of Auckland, New Zealand, has applied to join this Action.

E3.5.1.5 FP7 and Horizon 2020

Various projects have been funded, with many being applicable to vibroacoustics problems in general, with the emphasis being on transport. The various methods are also applicable to MDH. They include the following:

Mid-frequency "CAE Methodologies for Mid-Frequency Analysis in Vibration and Acoustics" (http://www.midfrequency.org). This was an EU FP7 Marie Curie Initial Training Network (ITN), coordinated by the Katholieke Universiteit Leuven. The consortium comprised Katholieke Universiteit Leuven, ISVR, University of Southampton, KTH Stockholm, LMT CACHAN, University of Cambridge, Ecole Centrale de Lyon, INSA Lyon, Universita Degli Studi Di Roma "LA SAPIENZA", EADS Astrium ST, LMS International, ViF - Virtual Vehicle Competence Centre, Daimler AG.

Mid-Mod "Mid-frequency vibro-acoustic modelling tools – Innovative CAE methodologies to strengthen European competitiveness." (http://www.mid-mod.eu/). The aims of this FP7 cooperation project centred on the development of CAE tools, applicable for the analysis of mid-frequency noise and vibration problems, and their application to industrial problems in the automotive and rail sectors. The consortium comprised Volvo Technology AB (coordinator), Katholieke Universiteit Leuven, ISVR University of Southampton, KTH Sweden, Università degli Studi di Firenze, Rheinisch-Westfälische, Technische Hochschule Aachen, Warsaw University of Technology, Volkswagen AG, Centro Ricerche Fiat S.C.p.A., LMS International, Bombardier Transportation, Virtuelle Fahrzeug (ViF).

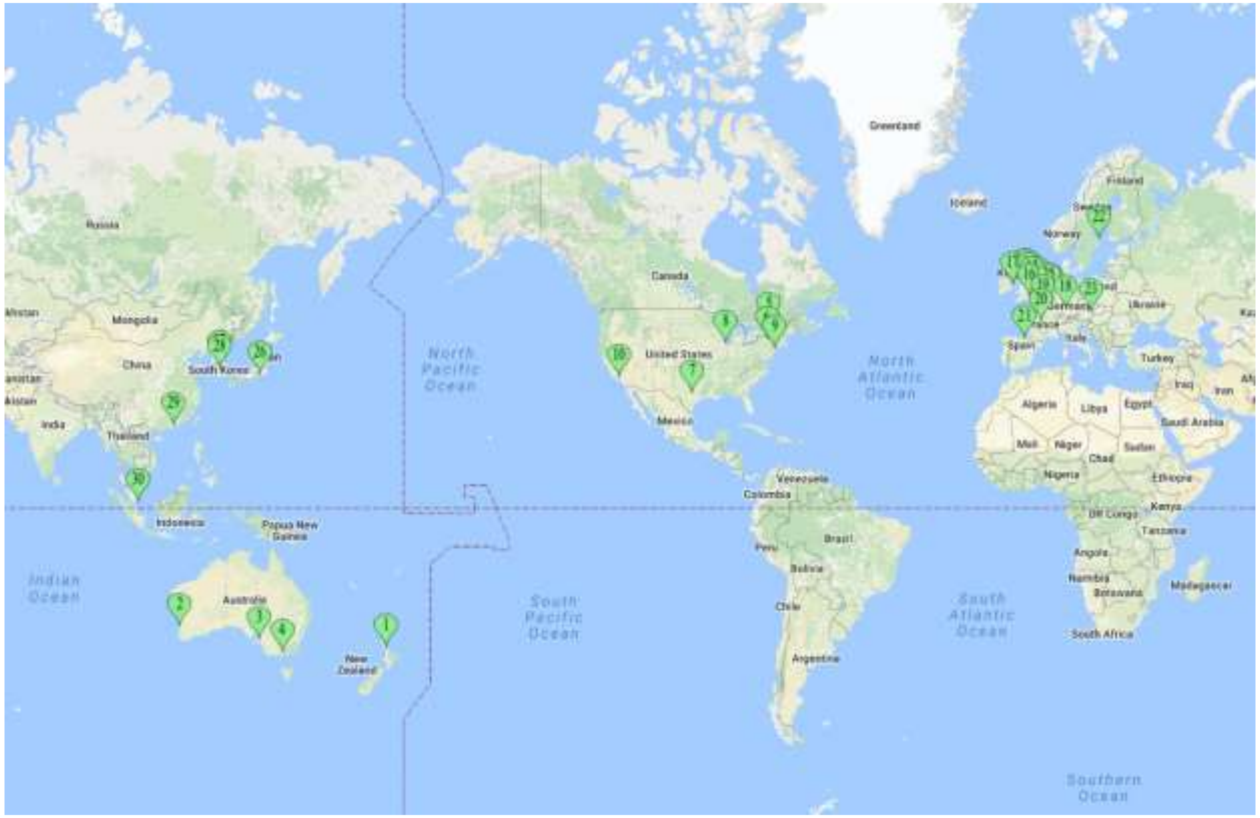
MIDEA "Midfrequency energy analysis" (http://www.inutech.de/midea/). This was an IAPP (Industry-Academia Partnerships and Pathways) involving the University of Nottingham and inuTech, with ISVR (Institute of Sound and Vibration Research) an Associate Partner. The aims were to develop the DEA method and incorporate it in inuTech's Diffpack software code.

Superpanels This was an IRSES project, concerned with staff secondment from within the EU to other institutions. The EU partners were the University of Naples (coordinator), ISVR and K.U. Leuven, the international partners being the University of Auckland and McGill University. The general subject concerned the performance, including the vibrational behaviour, of panels, laminates etc. One strand concerns vibro-acoustic performance.

E3.5.2 BUILDING ACOUSTICS TEST FACILITIES

The following list and map in Figure 15 are a selection of known, active building acoustic test facilities around the world. The test facilities have at least a reverberation chamber suite for building element (wall and floor) transmission loss measurement, many also have anechoic facilities and a few have flanking test facilities. Private company facilities not available for general, outsider use have been excluded.

Figure 15: Locations of building acoustics test facilities. Map produced by Grant Emms/Scion.



An interactive map can be found at

www.mapcustomizer.com/map/Building%20Acoustics%20Test%20Laboratories%20(numbered)

Oceania

1. The University of Auckland, Auckland New Zealand.
2. Acoustic Laboratories Australia, Perth, Australia
3. Acoustics Vibration and Control (AVC) Group, The University of Adelaide, Adelaide, Australia
4. Acoustic Testing Laboratory, CSIRO, Notting Hill, Australia

North America

5. NRC-CNRC, Ottawa, Ontario, Canada.
6. Intertek, Cortland, NY, US.
7. ETS-Lindgren Acoustic Research Laboratory, Cedar Park, Texas, USA.
8. Alion Riverbank Acoustical Laboratories, Geneva, IL, USA.
9. NGC Testing Services, New York, USA.
10. Western Electro-Acoustic Lab., Santa Clarita, CA, US

UK

11. Acoustics Research Group, University of Liverpool. UK

12. BRE, Cardington, UK.
13. University of Salford, Manchester, UK.
14. The Building Test Centre, (Saint Gobain), Leicestershire, UK.
15. SRL Technical Services, Suffolk, UK.
16. ISVR, University of Southampton, UK.

Europe

17. Ventac, Co Wicklow, Ireland.
18. Fraunhofer IBP, Suttgart, Germany.
19. European Laboratory of Building Acoustics at CSTB Marne-la-Vallée (and Grenoble), France.
20. Materials Testing Laboratory, Tarkett, France.
21. Tecnalia & Basque Government Laboratory for Quality Control in Dwellings, Vitoria, Spain.
22. Chalmers University,Sweden.
23. Akustik Center Austria, Holzforschung Austria,Austria.
24. Laboratory of Building Physics, KU Leuven, Belgium
25. Belgian Building Research Institute, Brussels, Belgium

Asia

26. Shimizu Corporation, Japan.
27. Korean Institute of Civil Engineering and Building Technology, Gyeonggi-do, Korea.
28. Acoustics Laboratory, Korea Institute of Machinery and Materials, Taejon, Korea.
29. Acoustics and Air Testing Laboratory, Hong Kong.
30. TÜV SÜD PSB, Singapore.

E3.5.3 BUILDING ACOUSTICS RESEARCH GROUPS

This section holds maps and lists of research groups that are active in the various areas of building acoustics. They are divided into Theoretical, Experimental and Subjective sub-groupings**.**

E3.5.3.1 Theoretical

Oceania

1. Acoustics Group, University of Auckland, Auckland, New Zealand.
2. University of Canterbury, Christchurch, New Zealand.
3. RMIT, Melbourne, Australia
4. School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney, Australia

Asia

5. Institute of Technology, SHIMIZU Corporation, 3-4-17 Ecchujima, Koto-ku, Tokyo, 135-8530, Japan
6. Faculty of Environmental and Urban Engineering, Kansai University, 3-3-35 Yamate-cho, Suita, 564-8680, Japan
7. Technology Center, Taisei Corporation, 344-1 Nase-cho, Totsuka-ku, Yokohama 245-0051, Japan
8. Acoustics Laboratory, Korea Inst. of Mach. and Materials, P.O. Box 101, Yusung, Taejon 305-600, South Korea

North America

9. National Research Council Canada, Construction, Ottawa, Canada
10. Department of Mechanical Engineering, Université de Sherbrooke, 2500 boul. de lUniversité, Sherbrooke, QC J1K 2R1, Canada

Figure 16: Locations of theoretical acoustics research groups. Map produced by Grant Emms/Scion.

11. Department of Chemical Engineering and Materials Science, University of Southern California, Los Angeles, CA 90089-0241, United States

UK

12. Acoustics Research Group, University of Liverpool. UK
13. University of Salford, Manchester, UK.
14. ISVR, University of Southampton, UK.
15. School of the Built Environment, Heriot-Watt University, Riccarton, Edinburgh, EH14 4AS, United Kingdom
16. University of Cambridge, Cambridge, United Kingdom

Europe

17. Université le Mans, France
18. C.S.T.B. (Centre Scientifique et Technique du Bâtiment), 24 Rue Joseph Fourier, Saint-Martin-d'Hères, France
19. Lund University, Lund, Sweden
20. CTBA, Technical Center for Wood and Furniture, Research Division, Allée de Boutaut, F-33 028 Bordeaux Cedex, France
21. School of Engineering, Linnaeus University, Sweden
22. University of Alicante, Department of Physics, System Engineering and Signal Theory, Alicante, Spain
23. Empa Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland
24. Technical University of Denmark, Acoustic Technology, Kongens Lyngby 2800, Denmark
25. KU Leuven, Department of Civil Engineering, 3000 Leuven, Belgium
26. Division of Sound and Vibration, Luleå University of Technology, 97187 Luleå, Sweden
27. Universitat Politècnica de Catalunya, Campus Nord, Jordi Girona 1, Barcelona, Spain

E3.5.3.2 Experimental

Oceania

1. Acoustics Group, University of Auckland, Auckland, New Zealand.
2. University of Canterbury, Christchurch, New Zealand.
3. RMIT, Melbourne, Australia
4. Acoustics Vibration and Control (AVC) Group, The University of Adelaide, Adelaide, Australia

Asia

5. Faculty of Environmental and Urban Engineering, Kansai University, 3-3-35 Yamate-cho, Suita, 564-8680, Japan
6. National Institute of Land Infrastructure Management, Tsukuba, Japan
7. Dept. of Architecture, College of Science and Technology, NIHON Univ., Tokyo, Japan
8. Acoustics Laboratory, Korea Inst. of Mach. and Materials, P.O. Box 101, Yusung, Taejon 305-600, South Korea
9. Department of Architectural Engineering, Hanyang University, Seoul, South Korea
10. Korean Institute of Civil Engineering and Building Technology, Gyeonggi-do, Korea.
11. Korea University, South Korea
12. China Academy of Building Research, Beijing, China

Americas

13. National Research Council Canada, Construction, Ottawa, Canada
14. Vibration and Acoustics Group, Federal University of Pará, Belém, PA, 66075-110, Brazil

UK

15. Acoustics Research Group, University of Liverpool. UK
16. University of Salford, Manchester, UK.
17. ISVR, University of Southampton, UK.
18. School of the Built Environment, Heriot-Watt University, Riccarton, Edinburgh, EH14 4AS, United Kingdom

Figure 17: Locations of experimental acoustics research groups. Map produced by Grant Emms/Scion.

Europe

19. C.S.T.B. (Centre Scientifique et Technique du Bâtiment), 24 Rue Joseph Fourier, Saint-Martin-d'Hères, France
20. Lund University, Lund, Sweden
21. CTBA, Technical Center for Wood and Furniture, Research Division, Allée de Boutaut, F-33 028 Bordeaux Cedex, France
22. Technical University of Denmark, Acoustic Technology, Kongens Lyngby 2800, Denmark
23. KU Leuven, Department of Civil Engineering, 3000 Leuven, Belgium
24. Division of Sound and Vibration, Luleå University of Technology, 97187 Luleå, Sweden
25. Norwegian University of Science and Technology, Trondheim, Norway
26. EMPA Swiss Federal Laboratories for Materials Science and Technology, Switzerland
27. Middle East Technical University, Department of Architecture, Turkey
28. Graz University of Technology, Austria
29. Acoustics Department, Building Research Institute, Ksawerów 21, 02 656 Warsaw, Poland

E3.5.3.3 Subjective

Oceania

1. Acoustics Group, University of Auckland, Auckland, New Zealand.

Asia

2. Department of Architectural Engineering, Hanyang University, Seoul, South Korea
3. Chonnam National University, 300 Yongbongdong, Gwangju, 500-757, South Korea
4. National Institute of Advanced Industrial Science and Technology (AIST), Chuo 6-11, AIST Tsukuba Central 6, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8566, Japan
5. Apex Level Standards and Industrial Metrology Division, CSIR-National Physical Laboratory, New Delhi, India

North America

6. National Research Council Institute for Research in Construction, 1200 Montreal Road, Ottawa, ON, K1A 0R6, Canada

UK

7. School of Architecture, University of Sheffield, Sheffield S10 2TN, United Kingdom
8. Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, United Kingdom

Europe

9. Institute of Transport Economics (TOI), Gaustadalléen 21, 0349 Oslo, Norway
10. Technical University of Denmark, Acoustic Technology, Kongens Lyngby 2800, Denmark
11. CSTB, 24 Rue Joseph Fourier, 38400 Saint-Martin-d'Hères, France

Figure 18: Locations of subjective acoustics research groups. Map produced by Grant Emms/Scion.

12. Engineering Acoustics, Lund University, Box 18, SE-22100, Lund, Sweden
13. Finnish Institute of Occupational Health, Lemminkäisenkatu 14-18 B, Turku, Finland
14. Luleå University of Technology, Sweden,
15. SBi, Danish Building Research Institute, Aalborg University, Dr. Neergaards Vej 15, DK-2970 Hørsholm, Denmark
16. Laboratory of Acoustics Soft Matter and Biophysics, KU Leuven, Celestijnenlaan 200D, Heverlee, Belgium
17. Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
18. Fraunhofer Institute for Building Physics, Nobelstrasse 12, 70569 Stuttgart, Germany

E4 Acoustic related organisations

E4.1 ACOUSTIC FOCUSED ORGANISATIONS

Most countries have their own acoustical societies but some key ones relevant to NZ are:

ASNZ – Acoustical Society of New Zealand www.acoustics.org.nz

AAAC – Association of Australasian Acoustic Consultants www.aaac.org.au
(prior to 2017 this was the Association of Australian Acoustic Consultants)

AAS – Australian Acoustical Society www.acoustics.asn.au

Acoustical Society of America – www.acousticalsociety.org

EAA - European Acoustics Association www.euracoustics.org

IoA – Institute of Acoustics www.ioa.org.uk "The UK's professional body for those working in Acoustics, Noise and Vibration."

Institute of Sound and Vibration Research http://www.southampton.ac.uk/engineering/research/centres/isvr.page

International Institute of Acoustics and Vibration www.iiav.org

International Commission for Acoustics – www.icacommission.org (US based)

ICA International Congress of Acoustics – held every 3 years, including 2016

Many of these sites provide resources with relevant technical information and research, including journals with academic research articles.

E4.2 NZ ORGANISATIONS WITH A FOCUS ON BUILDING DESIGN AND RESEARCH

When looking for information on NZ building design, construction and research, the BRANZ Website (Contacts > Links > Building –Related Organisations) has a very comprehensive list repeated below (BRANZ Website list of "Building Related Organisations" for reference from http://www.branz.co.nz/cms_display.php?sn=73&st=1&pg=15713 Nov 2016)
for reference followed by some notes on a few of these and a few extras. Members of Construction Industry Council (CIC) are also listed.

Arbitrators and Mediators Institute of NZ Inc (AMINZ)	www.aminz.org.nz
Architects - NZ Institute of (NZIA)	www.nzia.co.nz
Architectural Designers NZ Inc (ADNZ)	www.adnz.org.nz
Association of Consulting Engineers (ACENZ)	www.acenz.org.nz
Association of Wall and Ceiling Industries of New Zealand	www.awcinz.org.nz
Building & Construction Industry Training Organisation (BCITO)	www.bcito.org.nz
Building Industry Authority (BIA)	

(See Ministry of Business, Innovation and Employment - Building and Housing Group)	
Building Industry Federation of New Zealand	www.bif.org.nz
Building Officials Institute of NZ (BOINZ)	www.boinz.org.nz
Business NZ	www.businessnz.org.nz
Cement & Concrete Association of NZ (CCANZ)	www.ccanz.org.nz
Certified Builders Association of NZ Inc (CBANZ)	www.certified.co.nz
Claddings Institute of NZ (CINZ)	www.cinz.org.nz
Construction Information Ltd (CIL)	www.masterspec.co.nz
Design Association of NZ Inc (DANZ)	www.danz.co.nz
Designers Institute of NZ Inc (DINZ)	www.dinz.org.nz
Earth Building Association of NZ Inc (EBANZ)	www.earthbuilding.org.nz
Earthquake Commission (EQC)	www.eqc.govt.nz
Electrical Contractors Association of NZ Inc (ECANZ)	www.ecanz.org.nz
Energy Efficiency and Conservation Authority (EECA)	www.eeca.govt.nz
Fire Protection Association NZ Inc (FPANZ)	www.fireprotection.org.nz

Frame and Truss Manufacturers Association of NZ	www.ftma.co.nz
Heavy Engineering Research Association (HERA)	www.hera.org.nz
Housing NZ Corporation (HNZC)	www.hnzc.co.nz
Institute of Refrigeration, Heating & Air Conditioning Engineers of NZ Inc (IRHACE)	www.irhace.org.nz
Institution of Professional Engineers NZ (IPENZ)	www.ipenz.org.nz
Insurance Council of NZ (ICNZ)	www.icnz.org.nz
Landscape Industries Association of NZ	www.lianz.org.nz
Local Government NZ (LGNZ)	www.lgnz.co.nz
Master Painters NZ Assn Inc	www.masterpainters.co.nz
Master Plumbers, Gasfitters & Drainlayers NZ	www.masterplumbers.org.nz
Ministry of Business, Innovation and Employment – Building Performance (old Building and Housing Group and Building Industry Authority)	www.building.govt.nz
National Kitchen & Bathroom Associations NZ Inc (NKBA)	www.nkba.org.nz
NZ Concrete Society (NZCS)	www.concretesociety.org.nz
NZ Contractors' Federation Inc (NZCF)	www.nzcontractors.co.nz

NZ Fibrous Plaster Association	www.fibrousplaster.org
NZ Green Building Council (NZGBC)	www.nzgbc.org.nz
NZ Institute of Architects (NZIA)	www.nzia.co.nz
NZ Institute of Building (NZIOB)	www.nziob.org.nz
NZ Institute of Building Surveyors Inc (NZIBS)	www.buildingsurveyors.co.nz
NZ Institute of Landscape Architects (NZILA)	www.nzila.co.nz
NZ Institute of Quantity Surveyors Inc (NZIQS)	www.nziqs.co.nz
NZ Institute of Surveyors (NZIS)	www.surveyors.org.nz
NZ Joinery Manufacturers Federation	www.masterjoiners.co.nz
NZ Master Concrete Placers Association (NZMCPA)	www.mcpa.org.nz
NZ Metal Roofing Manufacturers Inc	www.metalroofing.org.nz
NZ Pine Manufacturers Association (NZPMA)	www.pine.net.nz
NZ Planning Institute (NZPI)	www.planning.org.nz
NZ Property Institute (NZPI)	www.property.org.nz
NZ Ready Mixed Concrete Association (NZRMCA)	www.nzrmca.org.nz
NZ Retail Interior Association (NZRIA)	www.nzria.co.nz
NZ Security Association (NZSA)	www.security.org.nz

NZ Specialist Trade Contractors' Federation Incorporated	www.nzstcf.org.nz
NZ Timber Industry Federation (NZTIF)	www.nztif.co.nz
Plastics New Zealand	www.plastics.org.nz
Precast NZ Inc	www.precastnz.org.nz
Property and Land Economy Institute of NZ (PLEINZ)	home.xtra.co.nz/hosts/pleinz
Property Council New Zealand	www.propertynz.co.nz
Registered Master Builders Federation Inc (RMBF)	www.masterbuilder.org.nz
Roofing Association of NZ (RANZ)	www.roofingassn.org.nz
Scion	
www.scionresearch.com	
Standards NZ (SNZ)	www.standards.co.nz
Window Association of NZ (WANZ)	www.wanz.org.nz
Wood Processors Association of NZ (WPA)	www.wpa.org.nz

Notes on a few extras:

- **BRANZ:** Building Levy research, studies, appraisals and general guidelines, education and feedback on building in NZ – www.branz.co.nz
- **BEACON Pathway Inc**: " The Society's objective is to transform New Zealand's homes and neighbourhoods to be high performing, adaptable, resilient and affordable"

http://www.beaconpathway.co.nz/about-us/
CRESA have done lots of the research for Beacon - www.cresa.co.nz/projects/beacon-pathway-research

- **CHRANZ** - **Centre for Housing Research Aotearoa NZ**, "Invest in rigorous, independent and relevant housing research to support policies and practices that meet New Zealand's changing and diverse housing needs through sustainable, affordable, good quality and responsive housing opportunities" http://thehub.superu.govt.nz/agency/centre-housing-research-aotearoa-new-zealand-chranz
- **LEVEL – the authority on sustainable building -** www.level.org.nz (BRANZ funded)
- **MBIE "Building performance"** website www.building.govt.nz is part of the Ministry for Business, Innovation and Employment (formed in 2012 from Ministry of Economic Development, the Department of Labour, Ministry of Science and Innovation and the Department of Building and Housing) www.mbie.govt.nz
  MBIE was formed from a number of other organisations which in their time also provided research and information that might be of use
  - MoRST– Ministry of Research ,Science and Technology to 2011 when merged with FRST to become MSI -> see MBIE
  - FRST – Foundation for Research Science and Technology 1990-2011, merged with MoRST to become Ministry of Science and Innovation (MSI) -> see MBIE
  - MSI -> Ministry of Science and Innovation 2011-2012, then incorporated into MBIE
  - DBH – Department of Building and Housing, to 2012 then incorporated into MBIE -> see MBIE
- **MFE:** Ministry for the Environment: www.mfe.govt.nz in relation to the Resource Management Act resources
- **Post Occupancy Evaluation** – C Watson Consultancy - www.postoccupancyevaluation.com for resident surveys once construction complete and resident moves in.
- **NZ Timber Design Society –** site dedicated to putting tools and information in the hands of designers of timber buildings

NZ Construction Industry Council (www.nzcic.co.nz): Members as at October 2016	
Research	
BRANZ (Building Research Association of NZ)	www.branz.co.nz
Hera (Heavy Engineering Research Association),	www.hera.co.nz
Design	
ADNZ (Architectural Designers NZ),	www.adnz.org.nz
The Designers Institute,	www.dinz.org.nz
NZIA (NZ Institute of Architects Inc),	www.nzia.co.nz
NZIQS (NZ Institute of Quantity Surveyors),	www.nziqs.co.nz
NZILA (NZ Institute of Landscape Architects)	www.nzila.co.nz
Engineering	
ACENZ (Association of Consulting Engineers),	www.acenz.org.nz

CCCANZ (Climate Control Companies Association NZ), www.ccca.org.nz

IPENZ (Institute of Professional Engineers NZ) www.ipenz.nz

Manufacturing

BIF (NZ Building Industry Federation) www.bifnz.co.nz

CCANZ (Cement & Concrete Association of New Zealand) www.ccanz.org.nz

NASH (National Association of Steel Frame Housing) www.nashnz.org.nz

WPMA (Wood Processing and Manufacturing Association of NZ) www.wpma.org.nz

Building

NZCBA (NZ Certified Builders Association www.nzcb.nz

CCNZ (Civil Contractors NZ) www.nzcontractors.co.nz

NZIOB (NZ Institute of Building) www.nziob.org.nz

RMBA (Registered Master Builders Association www.masterbuilder.org.nz

STCF (Specialist Trade Contractors Federation www.nzstcf.org.nz

Compliance

BOINZ (Building Officials Institute of NZ)www.boinz.org.nz

FPANZ (Fire Protection Association of NZ) www.fireprotection.org.nz

NZIBS (NZ Institute of Building Surveyors) www.buildingsurveyors.co.nz

SITESAFE www.sitesafe.org.nz

Property

PCNZ (Property Council NZ) www.propertynz.co.nz

PINZ (Property Institute NZ) www.property.org.nz

Innovation

NZGBC (NZ Green Building Council) www.nzgbc.org.nz

PREFABNZ www.prefabnz.com

APPENDIX F SAMPLE SOLUTION MODULE

The following pages provide an example of the type of document that could be created for Sample Solutions (eg sample floor/wall construction details), which could be made available through the hub. For more see Section 6.1.1.3

Note: Structure and checklists are based on Robust Details. Perspective drawings are from MBIE Proposed G6 documentation 2016 and reproduced with permission from MBIE

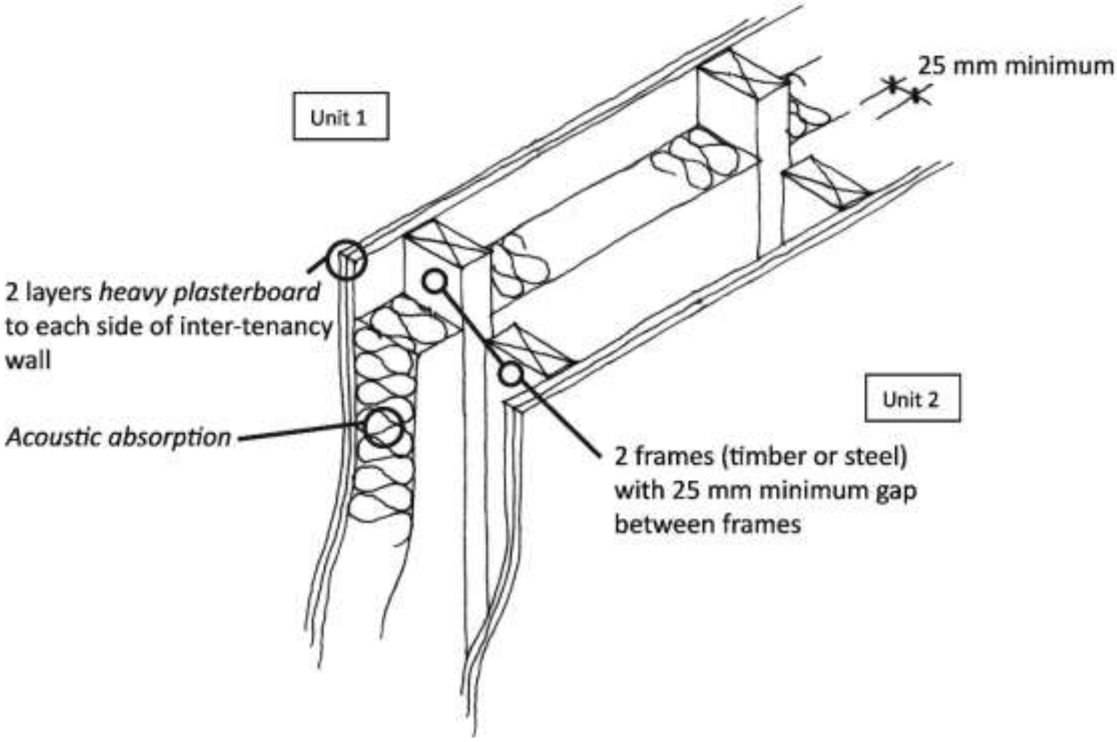
The performance of individual components will require reference in a separate section. BRANZ approval may be required for specific elements such as resilient pads to avoid overly complex technical specifications.

This module should not be used for technical guidance, but is intended to demonstrate the type of document that could be produced.

F1 Timber Framed Walls – WT

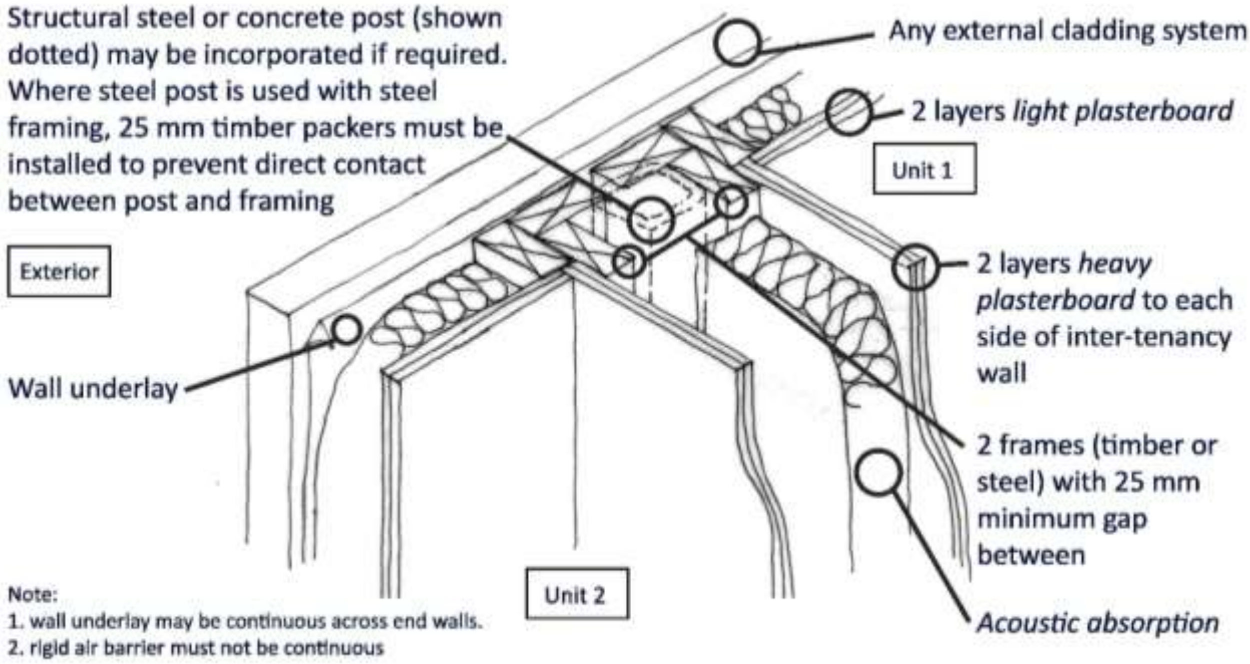
F1.1 WALL WT1 – DOUBLE STUD WALL

F1.1.1 WALL DESCRIPTION



Wall Width	• 150 mm (min) between inner faces of wall linings. • 25mm (min) gap between studs (**must not be bridged** by any diagonal bracing)
Wall lining	• 2 or more layers of heavy plasterboard (total nominal mass per unit area 22 kg/m2), both sides • All joints staggered • Seal all joints in outer layer with tape or caulk with sealant
Absorbent material	• 75 mm (min) fibreglass or polyester batts (density 10 – 60 kg/m^3).
Ties	• Resilient ties at no less than 1200 mm centres horizontally and no more than one row per storey height.

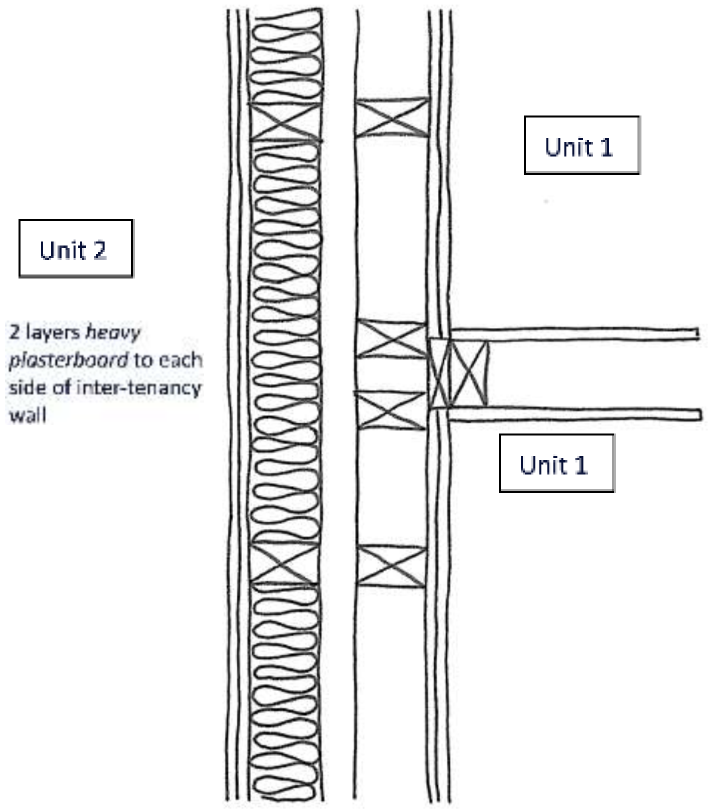
F1.1.2 EXTERNAL WALL JUNCTION



Comment: This is an example of a junction that could be refined following input from different disciplines, including architectural, fire, structural and façade engineers. The above detail utilises a double internal wall lining to suppress flanking noise via the external wall cavity. Closing this cavity off at the IT wall junction (for example using a heavy mineral wool blanket) would be more efficient but may cause issues with water tightness. The above detail also allows the main framing (if steel) to be connected to structural steel column with timber packers. Further guidance on these connections would be required to avoid confusion.

F1.1.3 INTERNAL WALL JUNCTION

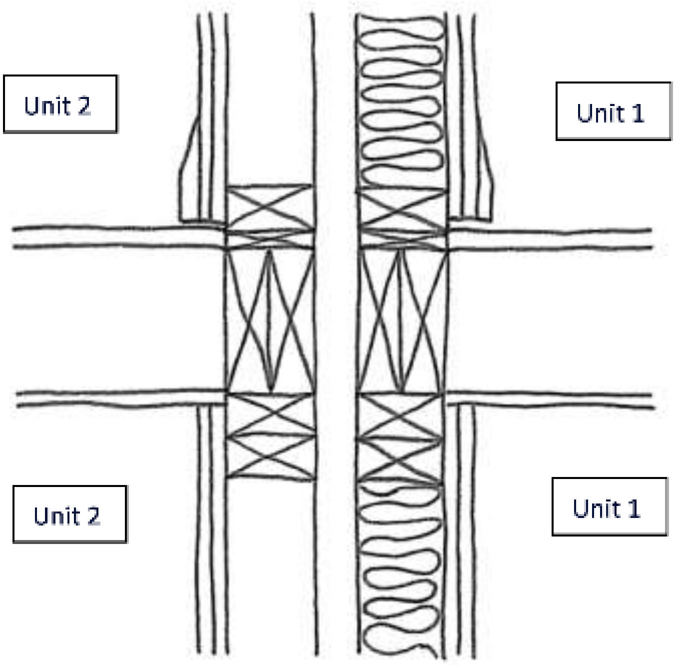
Plan view



- Seal all perimeter joints with tape or caulk with mastic

F1.1.4 INTERNAL FLOOR JUNCTION

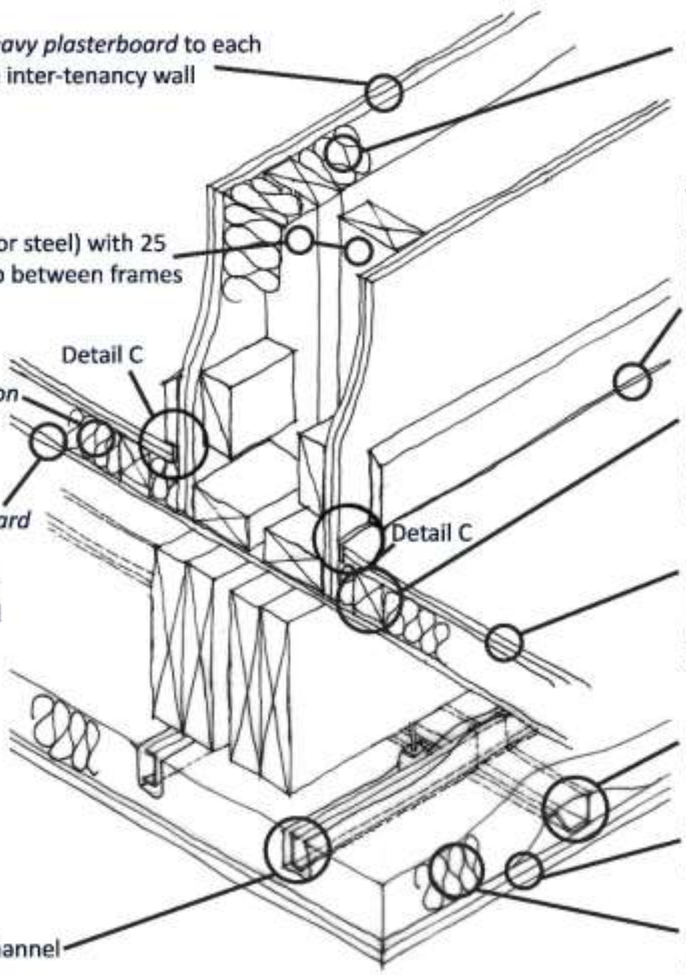
Section



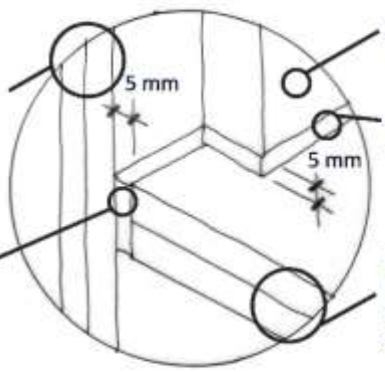
- Floor decking may run under sole plates
- Floor joists may span in either direction
- Internal floors should not be continuous between dwellings
- Close spaces between floor joists with full depth timber blocking where joists are at right angles to wall
- Seal all perimeter joints with tape or caulk with mastic

F1.1.5 SEPARATING FLOOR JUNCTION – LIGHTWEIGHT

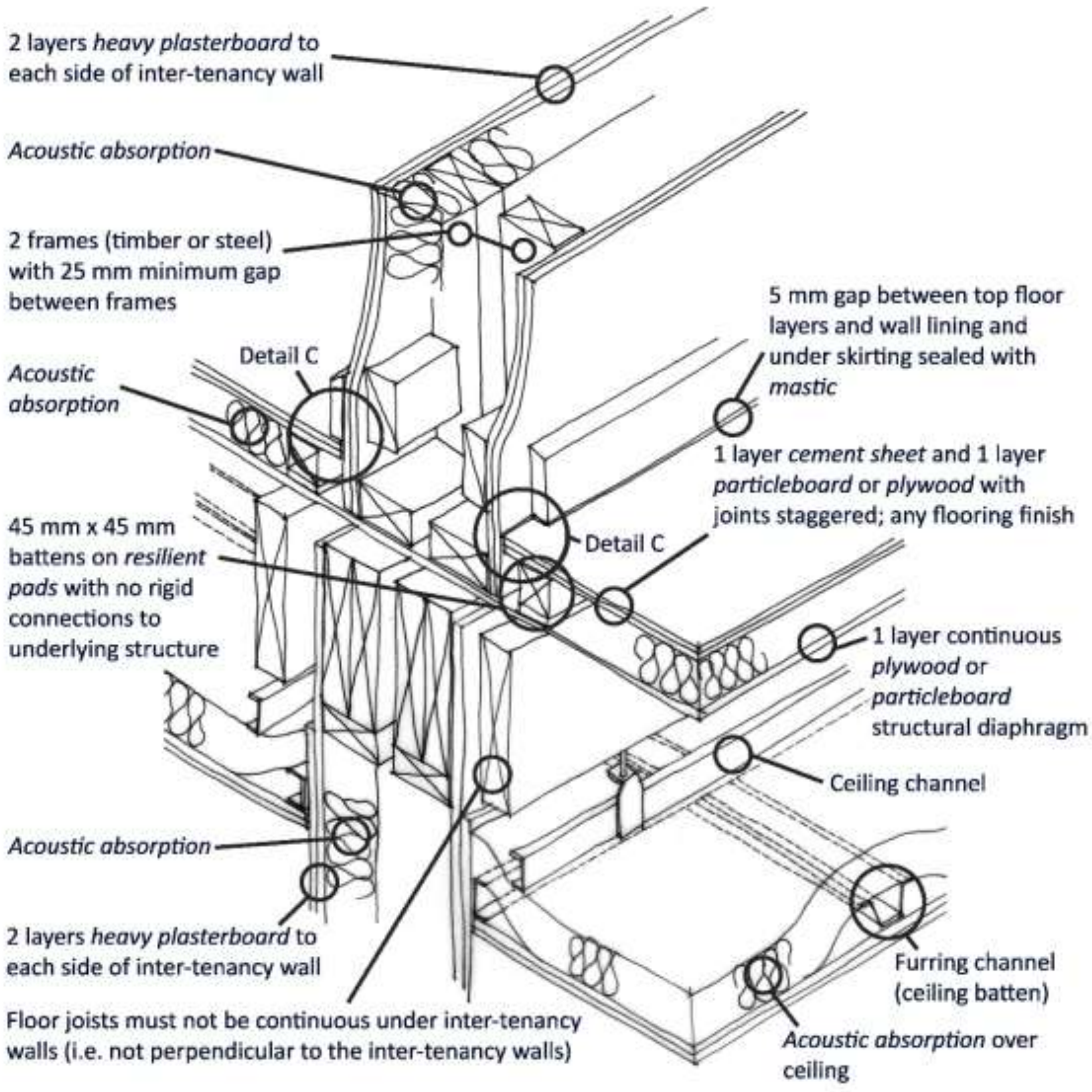
F1.1.5.1 Separating Floor Junction – Lightweight – no intertenancy wall below



Detail C

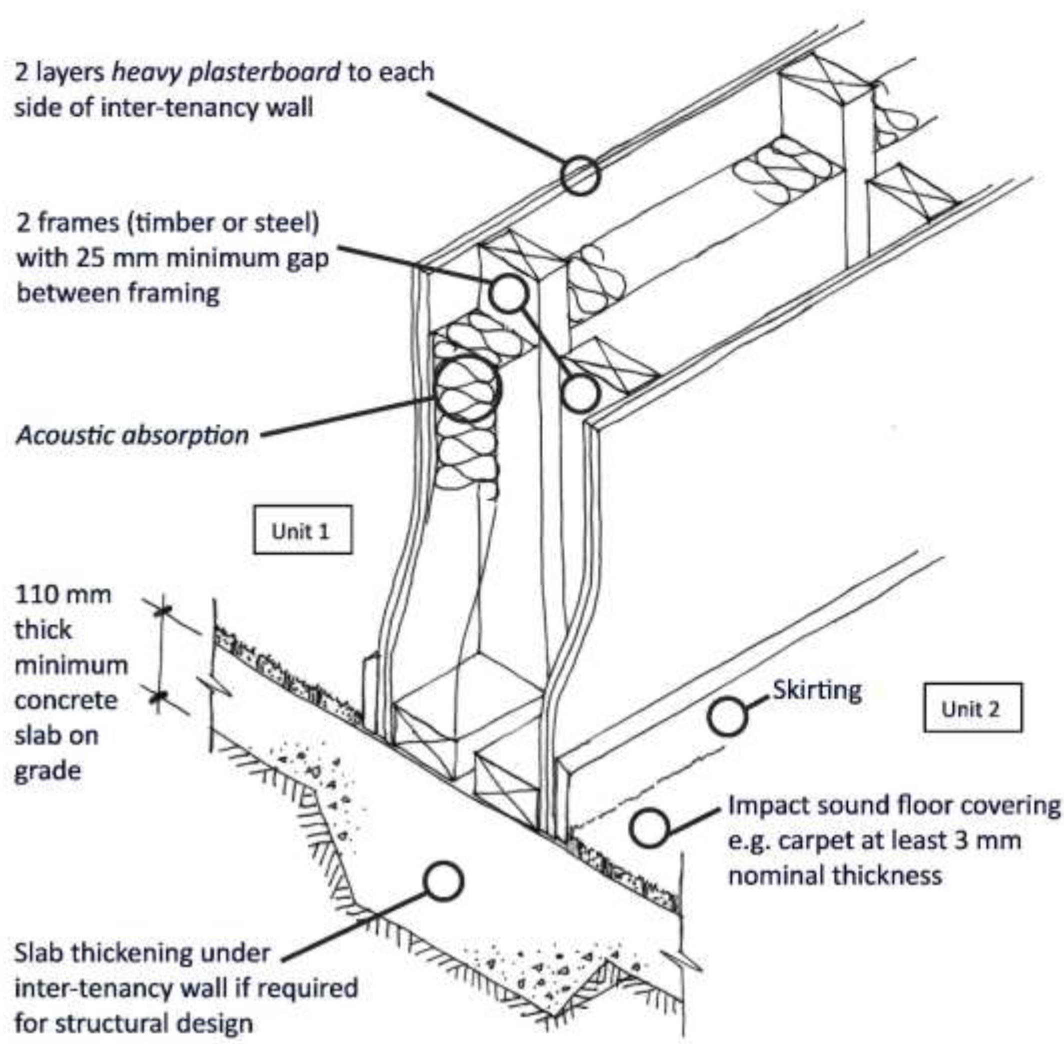


F1.1.5.2 Separating Floor Junction – Lightweight – intertenancy wall below

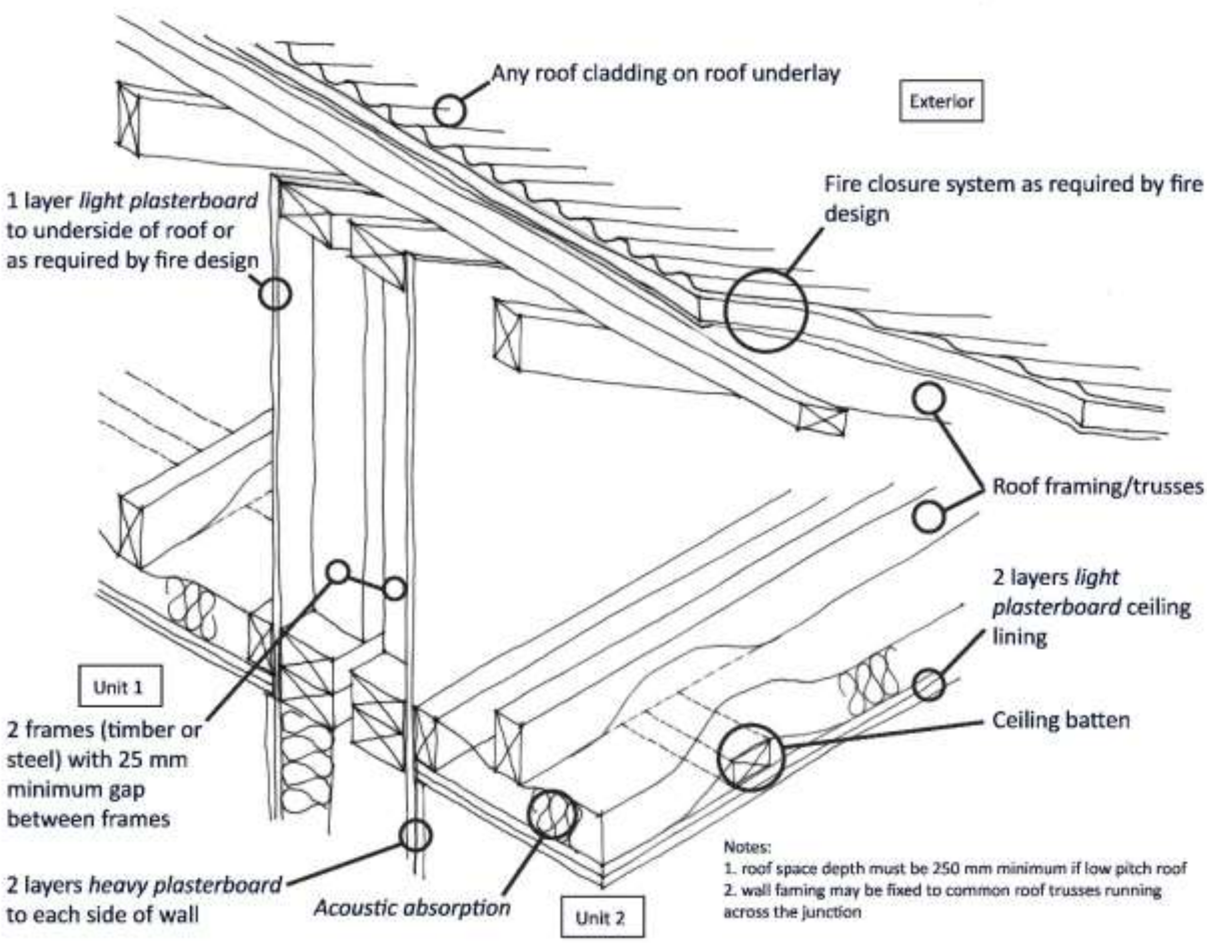


F1.1.6 GROUND FLOOR JUNCTION

F1.1.6.1 Common ground floor slab

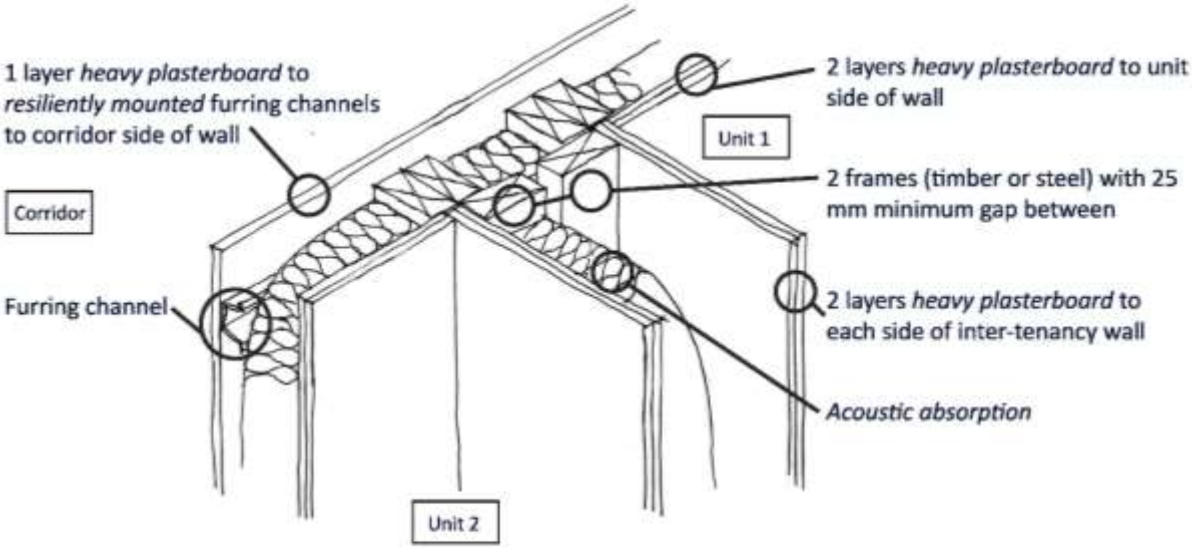


F1.1.7 ROOF JUNCTION

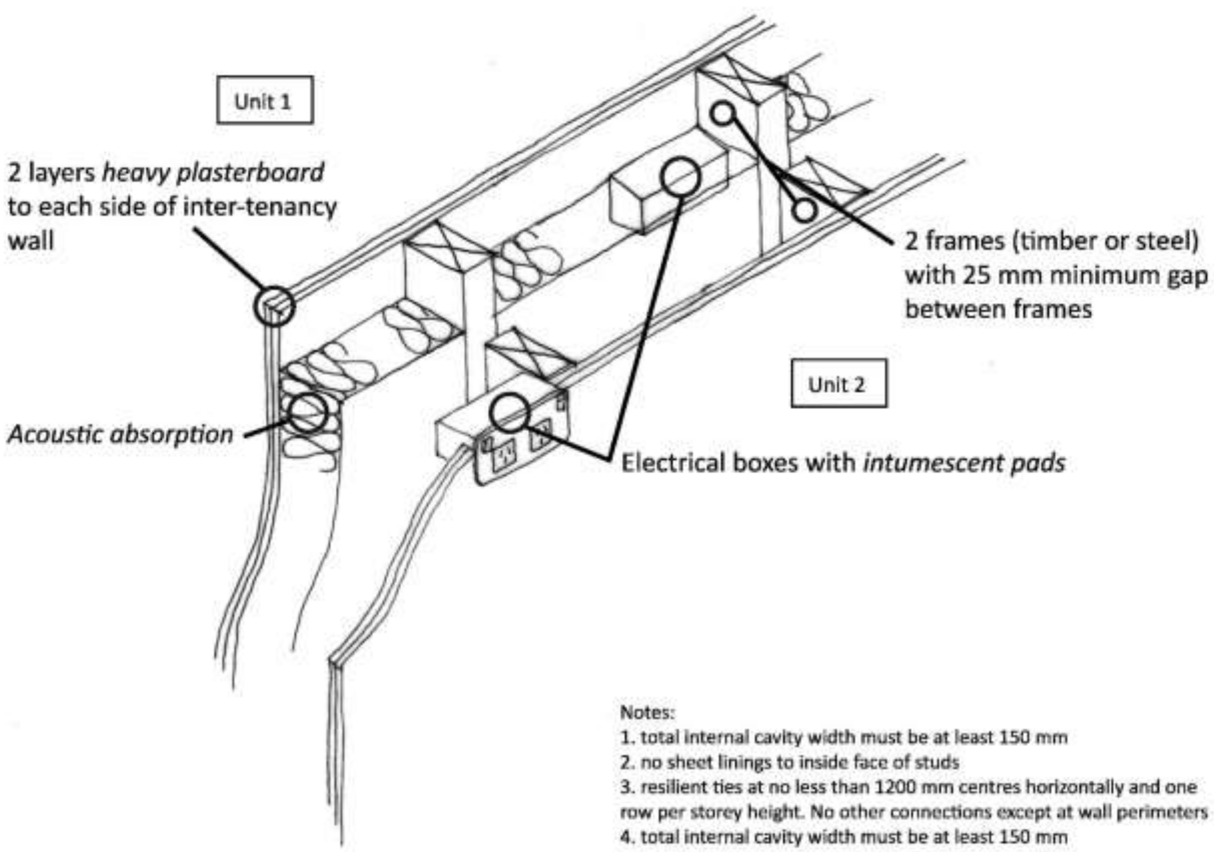


Comment: As commented for the external wall junction, this is a junction that it is expected could be refined following input from different disciplines. The above detail utilises a double internal ceiling lining to suppress flanking noise via the ceiling cavity. Closing this cavity off at the IT wall junction (for example using a heavy mineral wool blanket) would be more efficient but may cause issues with water tightness.

F1.1.8 JUNCTION WITH CORRIDOR WALL



F1.1.9 SERVICES AND SOCKETS IN SEPARATING WALL



Notes:
1. total internal cavity width must be at least 150 mm
2. no sheet linings to inside face of studs
3. resilient ties at no less than 1200 mm centres horizontally and one row per storey height. No other connections except at wall perimeters
4. total internal cavity width must be at least 150 mm

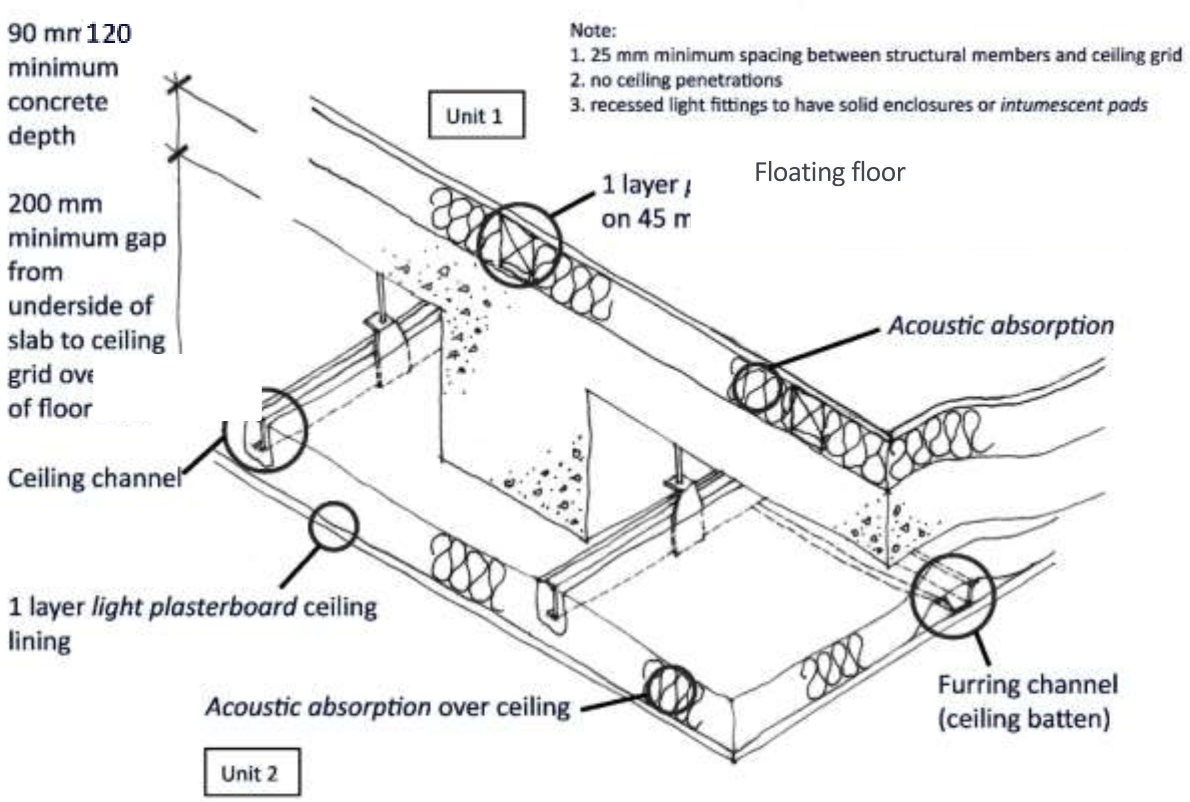
- Electrical boxes on opposite sides of the wall not to be within same stud cavity

F1.1.10 EXAMPLE CHECKLIST

	Checklist (to be completed by site manager/supervisor)			
	Company:			
	Site:			
	Site Manager/Supervisor			
		Inspected		
		Yes (√)	**No (√)**	Initials/date
Ref	**Item**			
1	Are wall linings at least 150 mm apart?			
2	Is there a minimum 25 mm gap between framing?			
3	Is absorbent material at least 75 mm thick?			
4	Does absorbent material cover whole lining area except above ceiling line in roof void zone?			
5	Are all joints in wall lining staggered?			
6	Is separating wall lining correct mass per unit area on both sides?			
7	Are all joints sealed with tape or caulked with sealant?			
8	If there is a separating floor (e.g. in flats/apartments) has the resilient flanking strip been provided?			
9	Is separating wall satisfactorily complete?			
	Notes (include details of any corrective action)			
	Site manager/supervisor signature			

F2 Concrete Floors

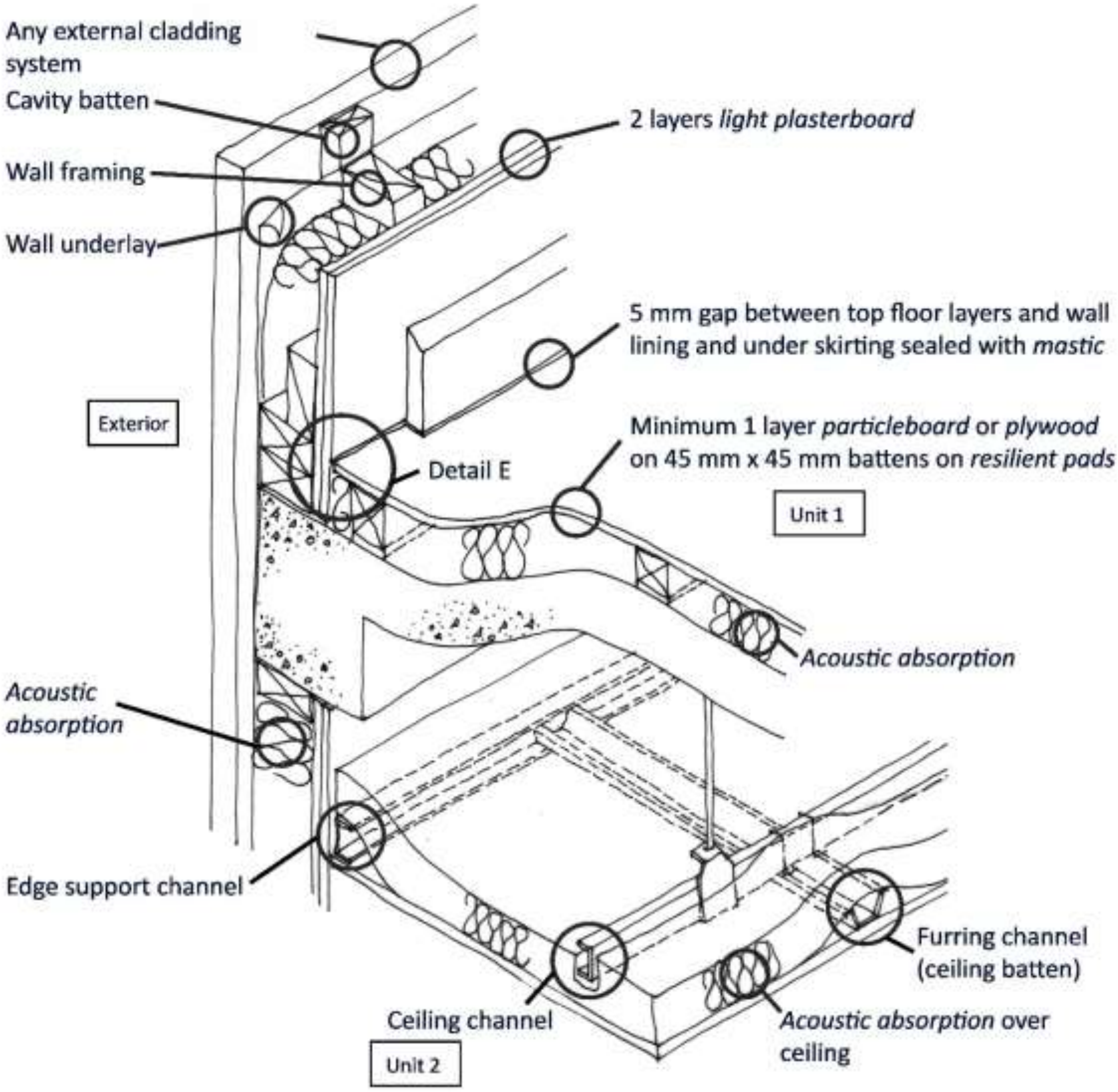
F2.1 FLOOR - FC1



Floating Floor	All floating floor treatments : a) Must achieve a minimum laboratory performance of ΔL_w=17dB b) Must be suitable and installed in accordance with the manufacturer's instructions. c) Require 5mm (min) resilient flanking strips around the perimeter of the flooring board to isolate floor from walls and skirting.
Structural floor	120 mm (min) concrete floor slab, 2400 kg/m^3 (min) density without screed,
Absorbent material	75 mm (min) fibreglass or polyester batts (density 10 – 60 kg/m^3.)
Ceiling	All ceiling joints must be sealed with tape or caulked with mastic The maximum load on resilient bars shall not exceed that specified in the manufacturer's instructions Provided there is a minimum ceiling void of 75mm recessed lighting may be installed in the ceiling: • in accordance with the manufacturer's instructions • at no more than one light per 2m^2 of ceiling area in each room • at centres not less than 0.75m

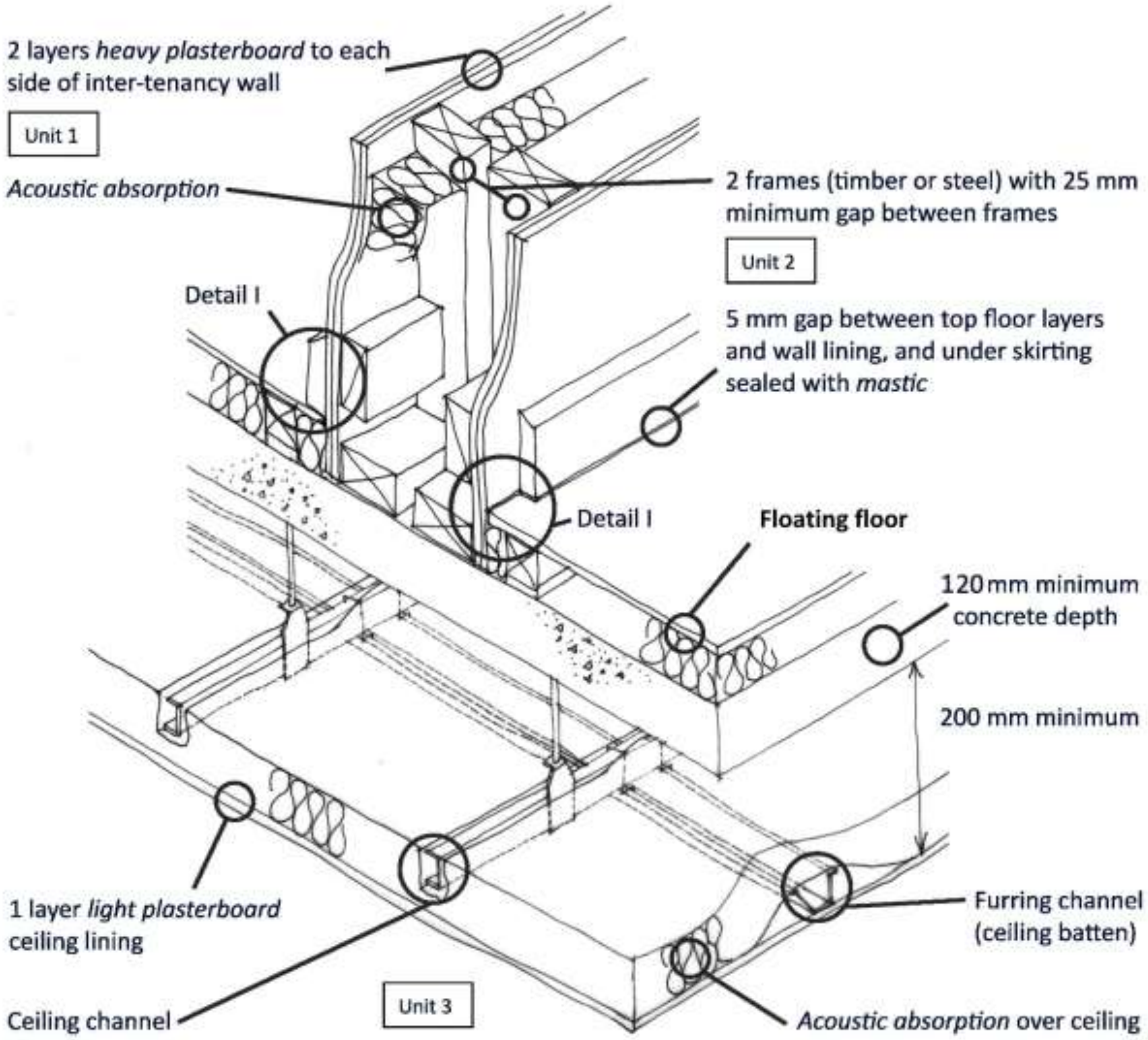
	• into openings not exceeding 100mm diameter or 100x100mm

F2.1.1 EXTERNAL WALL JUNCTION



Comment: As commented for the external wall junction, this is a junction that it is expected could be refined following input from different disciplines. The above detail utilises a double internal ceiling lining to suppress flanking noise via the ceiling cavity. Closing this cavity off at the IT wall junction (for example using a heavy mineral wool blanket) would be more efficient but may cause issues with water tightness.

F2.1.2 SEPARATING WALL JUNCTION



F2.1.3 CHECKLIST

	Checklist (to be completed by site manager/supervisor)			
	Company:			
	Site:			
	Site Manager/Supervisor			
		Inspected		
		Yes (√)	**No (√)**	Initials/date
Ref	**Item**			
1	Is concrete slab density 2400 kg/m³ (min)?			
2	Is the floor a minimum of 120mm (min) thick and of mass per unit area 280 kg/m² (min)?			
3	Is absorbent material in the ceiling cavity at least 75 mm thick?			
4	Has ceiling system been installed in accordance with the manufacturer's instructions (where applicable)?			
5	Are all ceiling board joints sealed with tape or caulked with mastic?			
6	Is separating wall lining correct mass per unit area on both sides?			
7	Has floating floor treatment been installed in accordance with the manufacturer's instructions?			
8	Have all resilient flanking strips been fitted?			
9	Is separating floor satisfactorily complete?			
	Notes (include details of any corrective action)			
	Site manager/supervisor signature			

APPENDIX G STAGE 2 INDUSTRY CONSULTATION (SEPARATE DOCUMENT)

Given the large size of this appendix, this is available as a separate pdf. Study report pdf 2 of 2.

This appendix provides details of the industry consultation conducted during Stage 2, including survey methodology and question by question analysis of the survey results.

APPENDIX H TOWARD QUIET HOUSING SURVEY RAW INFO (AVAILABLE UPON REQUEST)

This Appendix is available on request from BRANZ.

Collation of responses by survey question, including counts of responses for multi-choice answers and tables of comments / text responses identified only by role category.