Knock on Wood:
Acoustical Design in Mass Timber Structures

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ARUP

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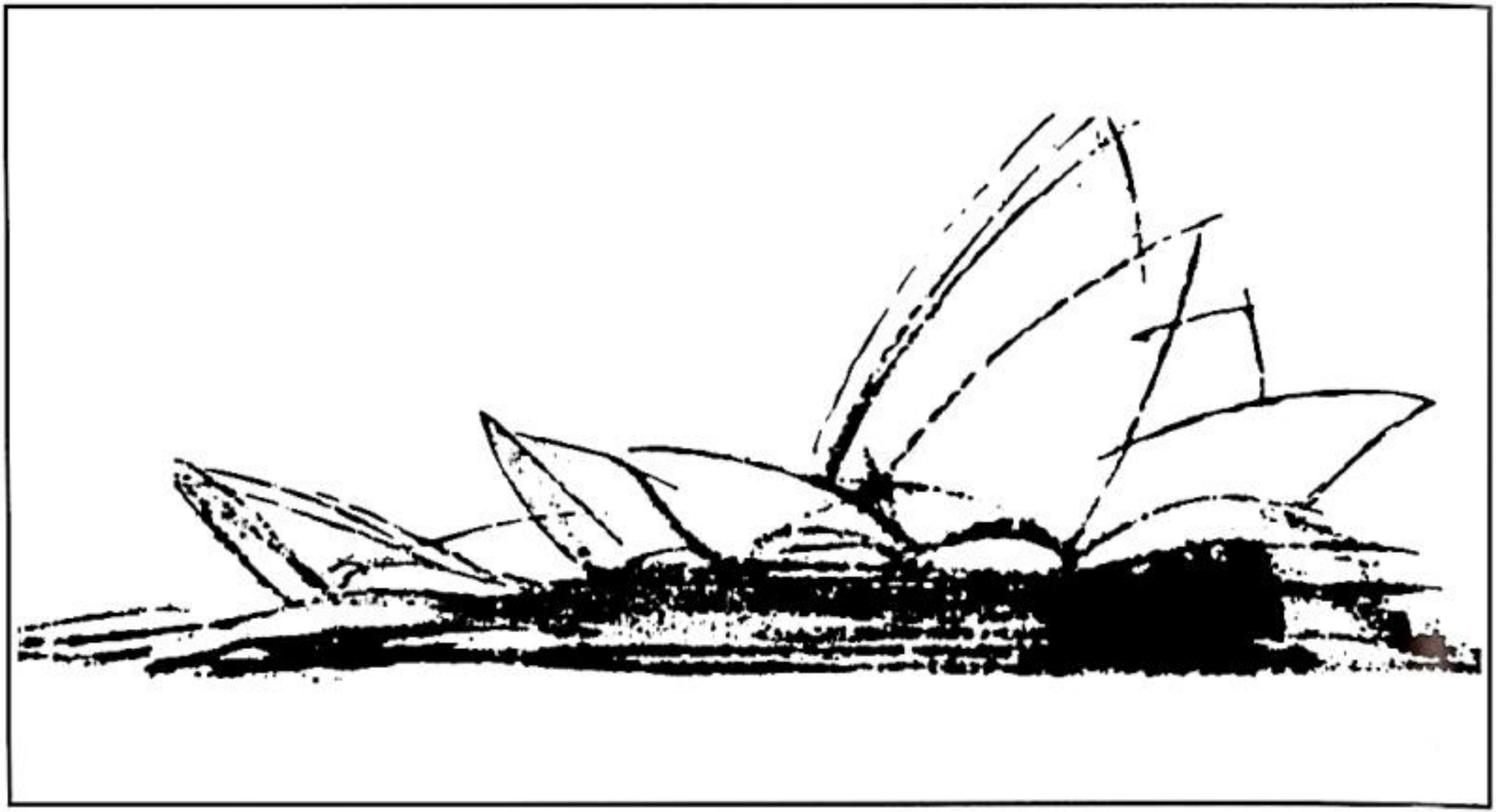
Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Course Description

The use of mass timber in multi-family and commercial buildings presents a complex set of acoustic challenges. While laboratory measurements of the impact and airborne sound isolation of traditional building assemblies, such as concrete, steel, and light wood-frame, are widely available, fewer resources exist that quantify the acoustic performance of mass timber assemblies, including cross-laminated timber (CLT) and nail-laminated timber (NLT) systems. Furthermore, acoustical professionals are not typically retained for mass timber projects, placing the acoustic responsibilities on the design team. This presentation will review common mass timber assemblies and acoustical rules of thumb for architects and designers. Topics will include detailing strategies, options for eliminating flanking paths, and best-practices for achieving good acoustic performance in mass timber buildings.

Learning Objectives

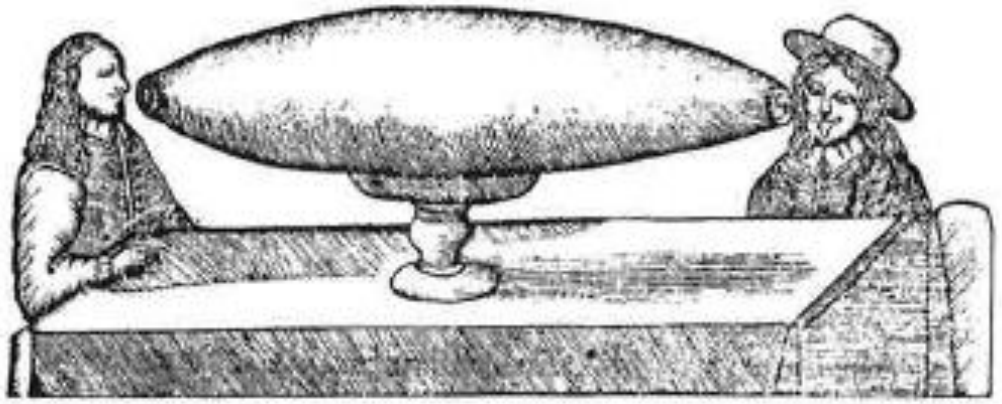
1. Highlight the fundamental differences between mass timber and other construction materials in terms of their acoustical performance.
2. Demonstrate common mass timber floor assemblies, including those with CLT and NLT, and discuss effective noise barrier techniques used in these assemblies.
3. Explore detailing strategies for mass timber assembly interfaces that minimize flanking and increase acoustical performance.
4. Review acoustically-tested mass timber assemblies and resources available to designers.



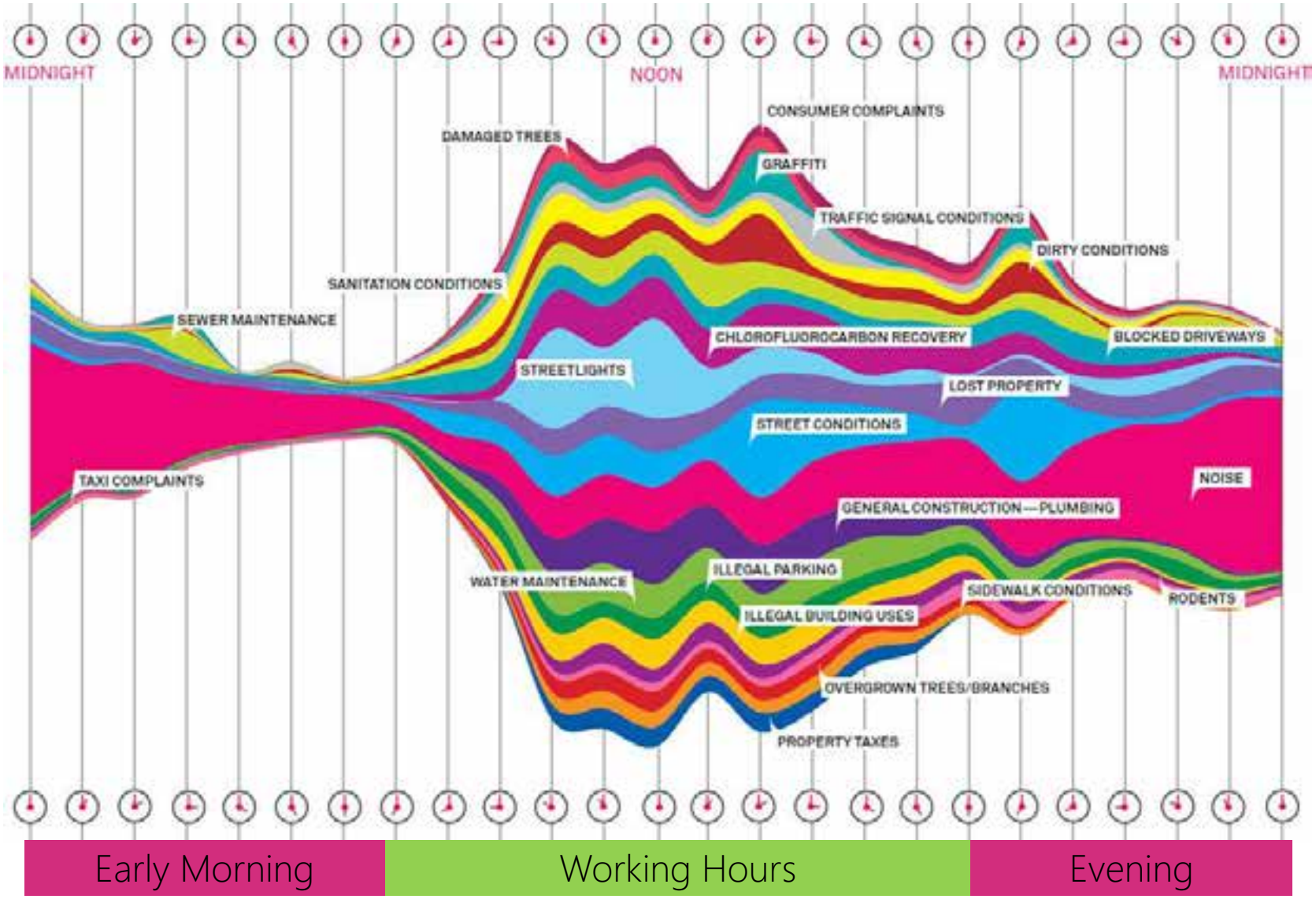
Early Noise Ordinances

No man shall after the houre of nine at the Night, keepe any rule whereby any such suddaine out-cry be made in the still of Night, as making any affray, or beating hys Wife, or servant, or singing, or revyling in his house, to the Disturbaunce of his neighbours"

Rule 30, The Lawes of the Market, 1595

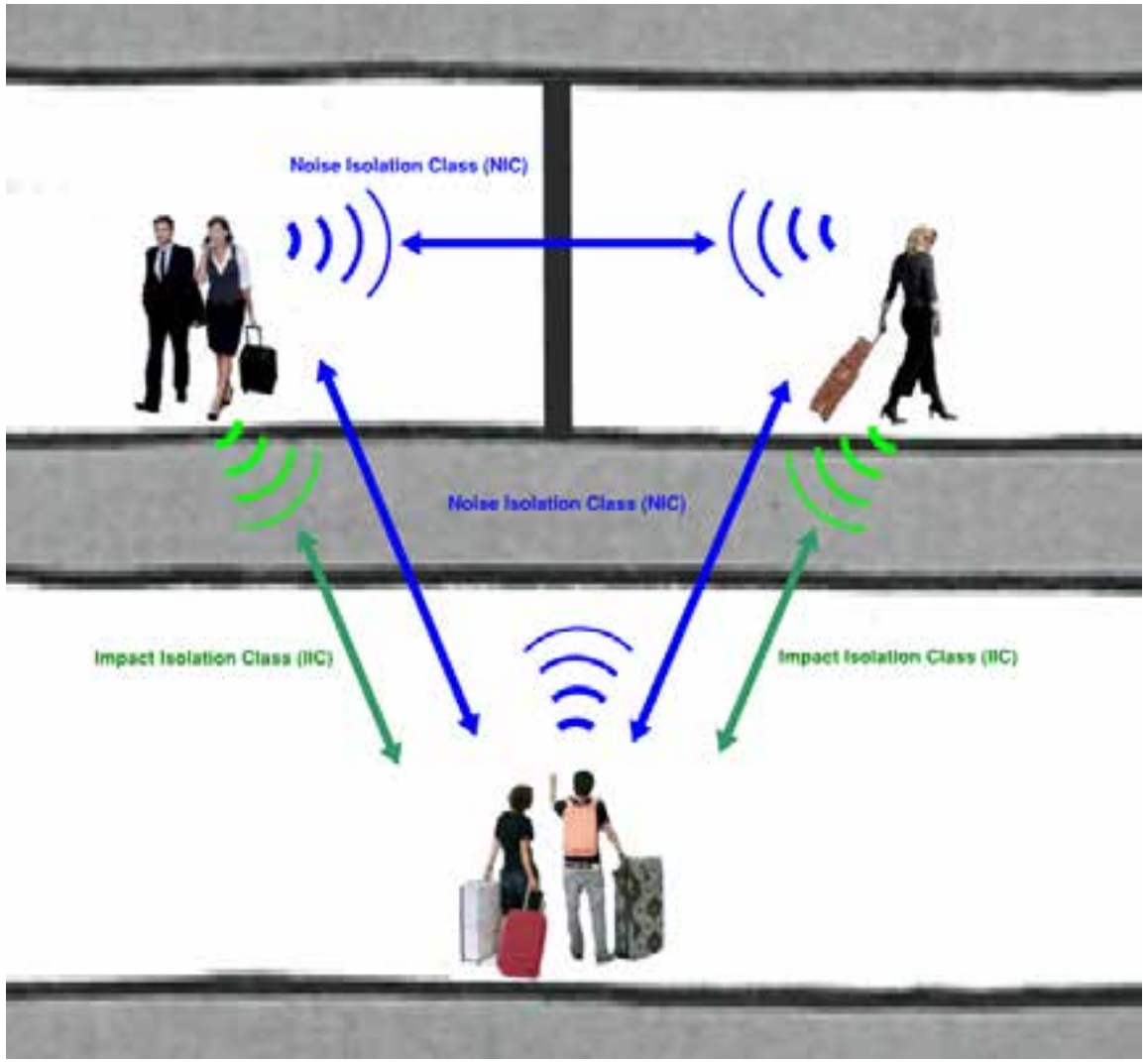


What a Hundred Million Calls to 311 Reveal About New York



Acoustics in Buildings

Key Issues in Timber Assemblies



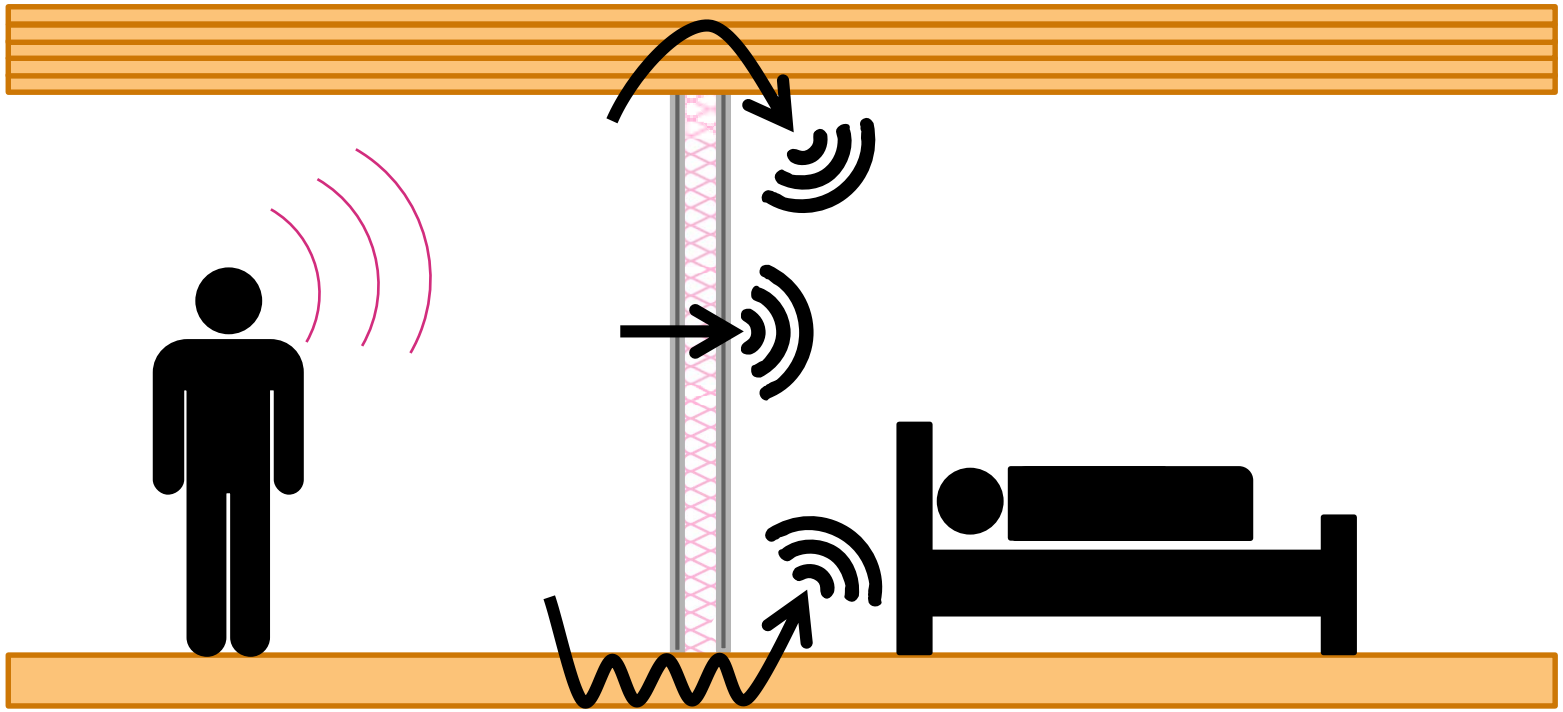
- Sound isolation rating systems:
  - Airborne sound isolation (STC, Sound Transmission Class).
  - Impact sound isolation (IIC, Impact Isolation Class)
- Architectural aesthetics vs sound isolation
- Flanking conditions (junction detailing) – implications for stability, mass, and complexity

Airborne Sound Transmission (STC)

Airborne sound can be transmitted:

- "Through" partitions
- Around partitions (i.e. flanking paths)
- Through structural coupling

Airborne sound isolation is classified using the **Sound Transmission Class** (**STC**) rating of an assembly.

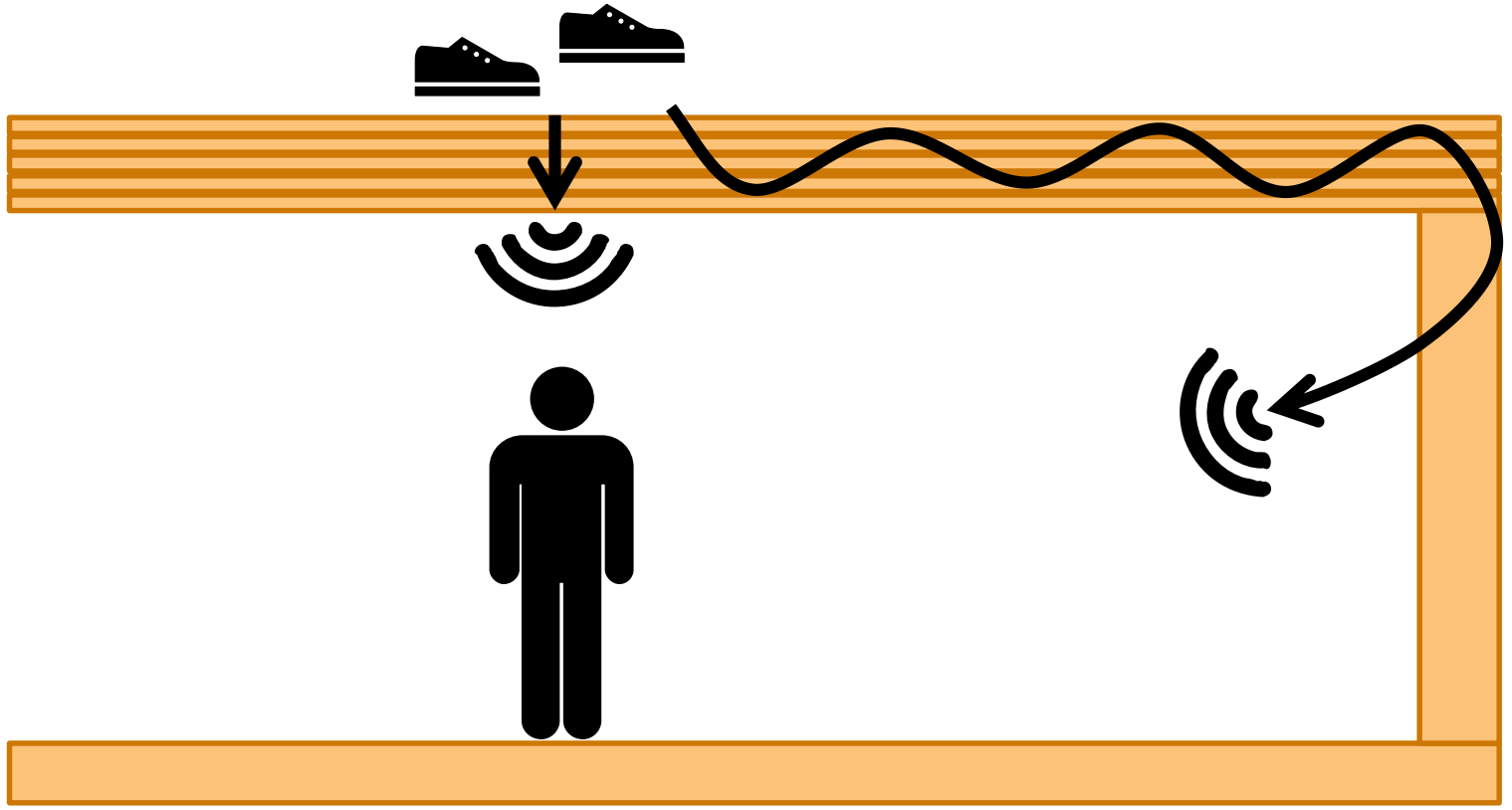


Impact Sound Isolation (IIC)

Impact sound can be transmitted:

- Through floor assemblies
- Through structural coupling

Impact sound isolation is classified using the **Impact Insulation Class** (**IIC**) rating of an assembly.



Mass Timber vs Traditional Construction

The acoustic performance of building materials is a multi-faceted issue:

Construction Type	Mass	Acoustic Detailing Sensitivity	Performance Data, Predictive Methods and Experience in Market
Concrete	✓ ✓ ✓	✓	✓ ✓ ✓
Mass Timber	✓ ✓	✓ ✓	✓
Traditional Stick-Frame	✓	✓ ✓ ✓	✓ ✓ ✓

What does code require?

International Building Code

The two most commonly used guidelines for multi-family dwelling acoustic design requirements are the International Building Code and the U.S. Department of Housing and Urban Development guide. Adopted from the Universal Building Code (1988)

The 2015 International Building Code (IBC) requires per Section 1207.2 and Section 1207.3:

STC 50 airborne sound separation (45 in the field, minimum)

IIC 50 impact isolation class (45 in the field, minimum)

SECTION 1207
SOUND TRANSMISSION

1207.1 Scope. This section shall apply to common interior walls, partitions and floor/ceiling assemblies between adjacent *dwelling units* and *sleeping units* or between *dwelling units* and *sleeping units* and adjacent public areas such as halls, *corridors*, *stairways* or *service areas*.

1207.2 Air-borne sound. Walls, partitions and floor/ceiling assemblies separating *dwelling units* and *sleeping units* from each other or from public or service areas shall have a sound transmission class of not less than 50, or not less than 45 if field tested, for air-borne noise when tested in accordance with ASTM E 90. Penetrations or openings in construction assemblies for piping; electrical devices; recessed cabinets; bathtubs; soffits; or heating, ventilating or exhaust ducts shall be sealed, lined, insulated or otherwise treated to maintain the required ratings. This requirement shall not apply to entrance doors; however, such doors shall be tight fitting to the frame and sill.

1207.2.1 Masonry. The sound transmission class of concrete masonry and clay masonry assemblies shall be calculated in accordance with TMS 0302 or determined through testing in accordance with ASTM E 90.

1207.3 Structure-borne sound. Floor/ceiling assemblies between *dwelling units* and *sleeping units* or between a *dwelling unit* or *sleeping unit* and a public or service area within the structure shall have an impact insulation class rating of not less than 50, or not less than 45 if field tested, when tested in accordance with ASTM E 492.

Acoustic Design "Guidelines"

- ICC G2-2010 Guideline for Acoustics
- American Hospital Associate (for healthcare facilities)
- ANSI S12.60 (for K-12 schools)
- Department of Housing and Urban Development (for multi-family housing)
- GSA (for federal courthouseings and office buildings)
- THX (for cinema)

…but these are just guidelines…not code requirements…

ICC G2 - 2010 Acoustics

Table 2: Grades of Laboratory Acoustical Performance

Laboratory Sound Rating	Acceptable Performance (Grade B Performance)	Preferred Performance (Grade A Performance)
Airborne Sound (STC per ASTM E 90)	55	60
Impact Sound (IIC per ASTM E 492)	55	60

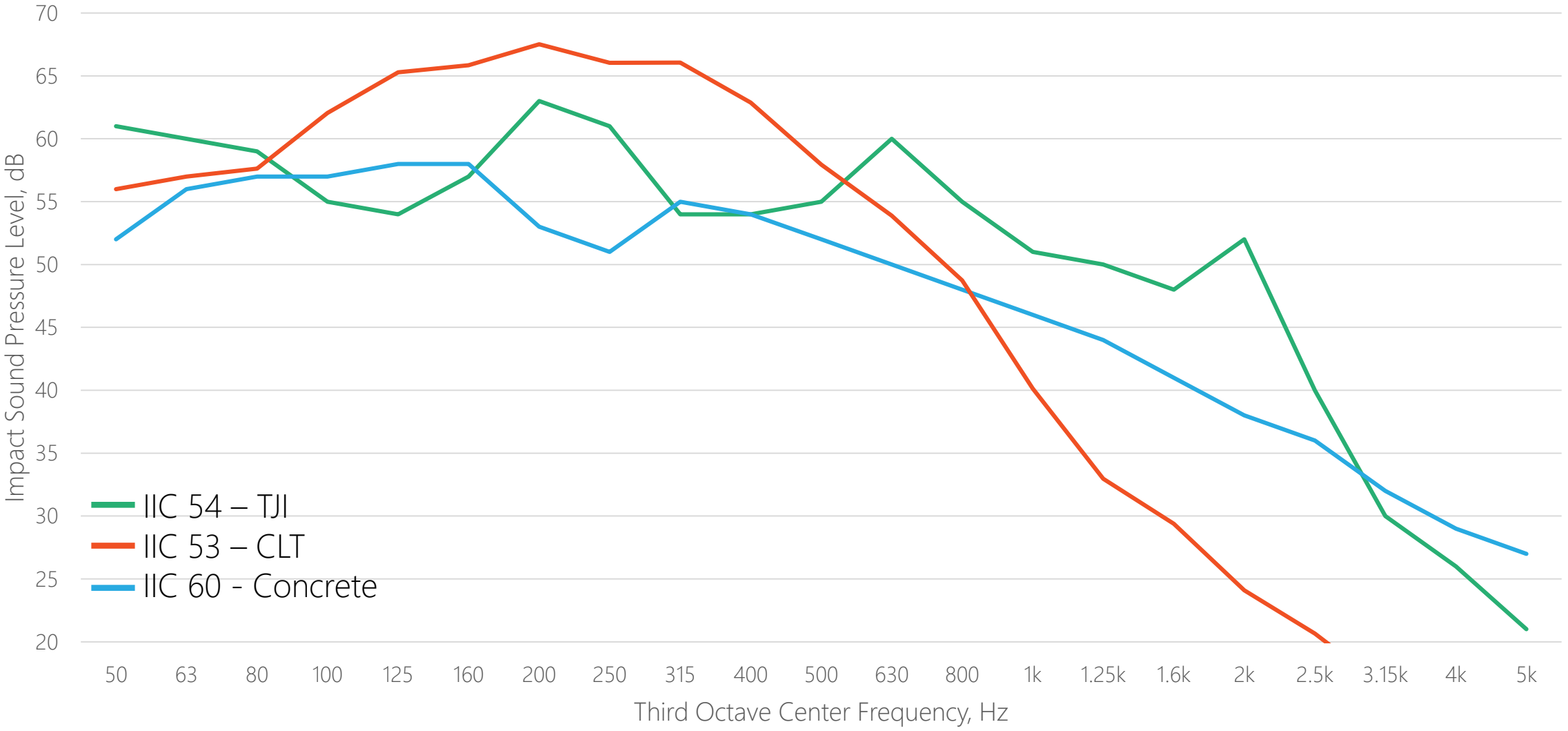
Table 1: Grades of Field Acoustical Performance

Field Sound Rating	Acceptable Performance (Grade B Performance)	Preferred Performance (Grade A Performance)
Airborne Noise (NNIC per ASTM E 336)	52	57
Impact Noise (NISR per ASTM E 1007)	52	57

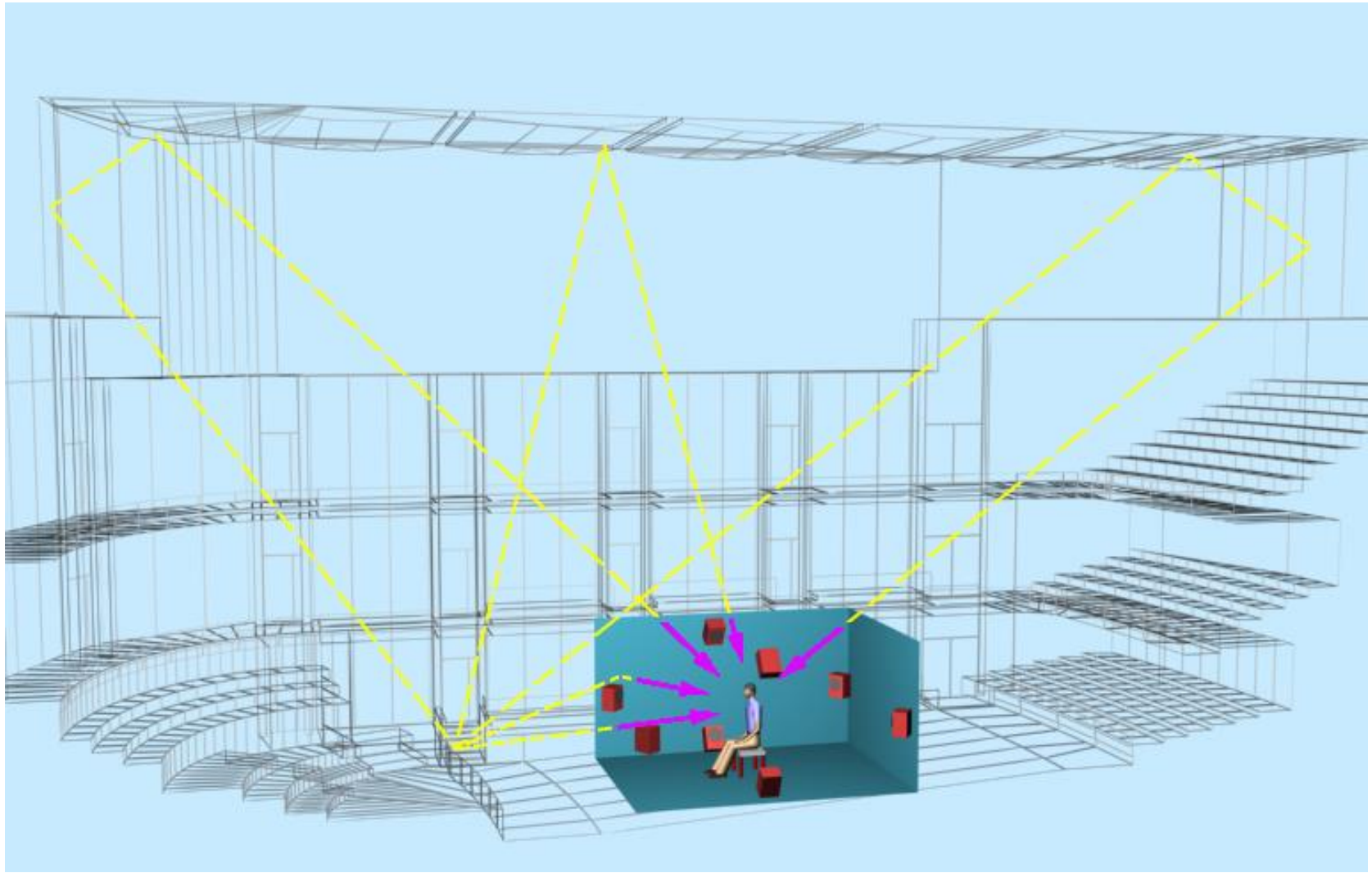
"…a large percentage of people are ***highly annoyed*** by noises from their neighbors, leading to a ***reduced quality of life*** and possibly to negative health effects."

What is the *"right"* level of acoustic performance?

How do acoustic metrics correlate with our perception of sound?



Design by Listening



Acoustic Concepts for Mass Timber Buildings

Floor Assembly Design

- Three components for minimum viable CLT assembly:
  1. CLT
  2. Resiliency
  3. Mass

- CLT provides structural support and mass
- Resilient layer provides mechanical decoupling to reduce the transfer of vibration
- Mass provides weight to mitigate the transfer of low frequencies

- Finish floor and acoustic underlayment to further reduce high frequencies and provide decoupling

From the CLT Handbook – Assembly 15.1

Testing, Testing, Testing

- Acoustic lab testing used to ensure mass timber floor assemblies perform as expected/predicted

- Resources include:
  - National Research Council Canada
  - CLT Handbook
  - Manufacturers

In-Situ Acoustic Testing

1. Airborne sound isolation of mass timber floor assemblies per *ASTM E336: Standard Test Method for Measurement of Airborne Sound Insulation in Buildings*
2. Impact sound isolation of mass timber floor assemblies per *ASTM E1007: Standard Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling Assemblies and Associated Support Structures*
3. The low frequency (50-250 Hz) airborne and impact sound isolation of floor assemblies not included in *ASTM E336*

We used the following equipment (see images to right for make and model):

(2) Calibrated Type 1 sound pressure level meters
(1) Self-calibrating ASTM approved tapping machine for impact insulation testing
(2) Signal generator
(1) Noise source loudspeaker

sound pressure level meter

tapping machine

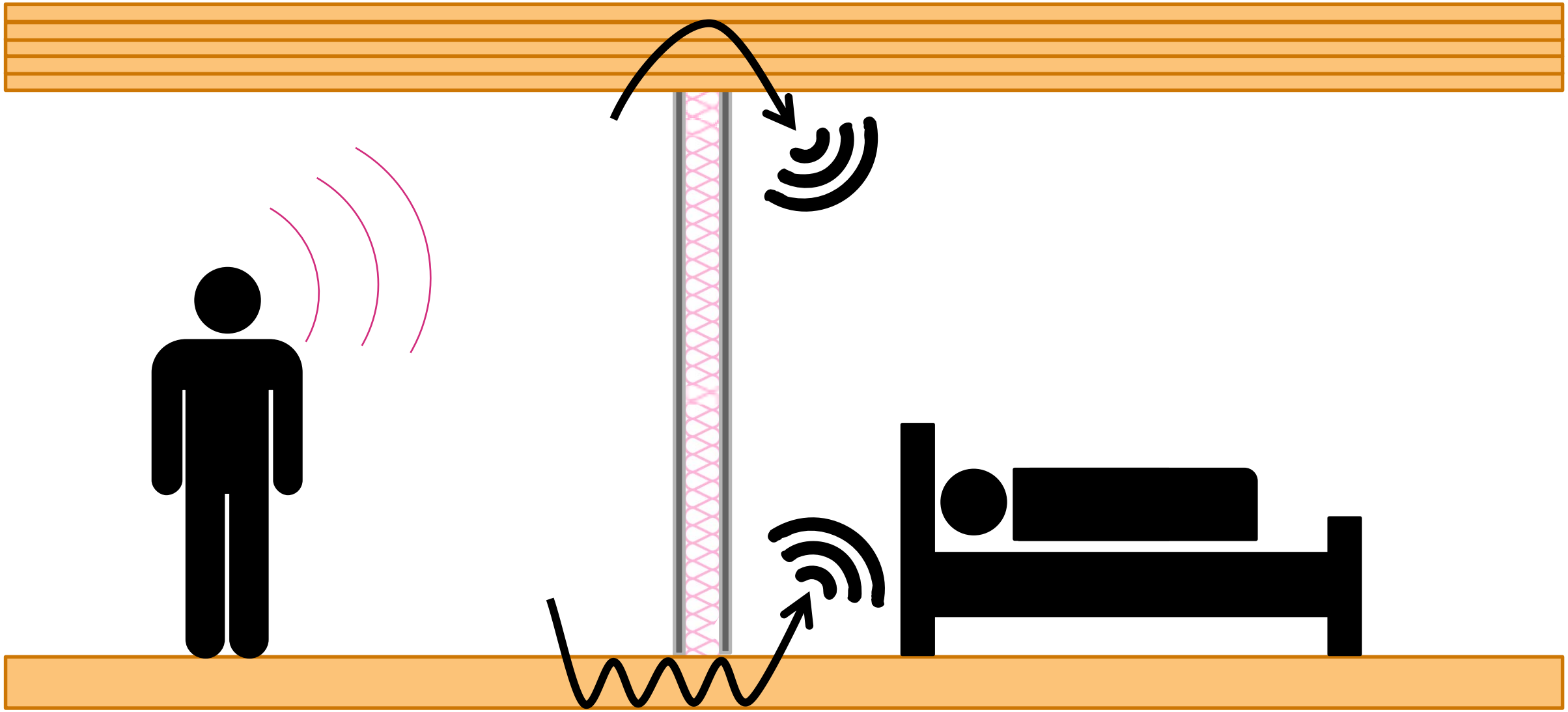
Impact sound testing

Airborne sound testing

signal generator

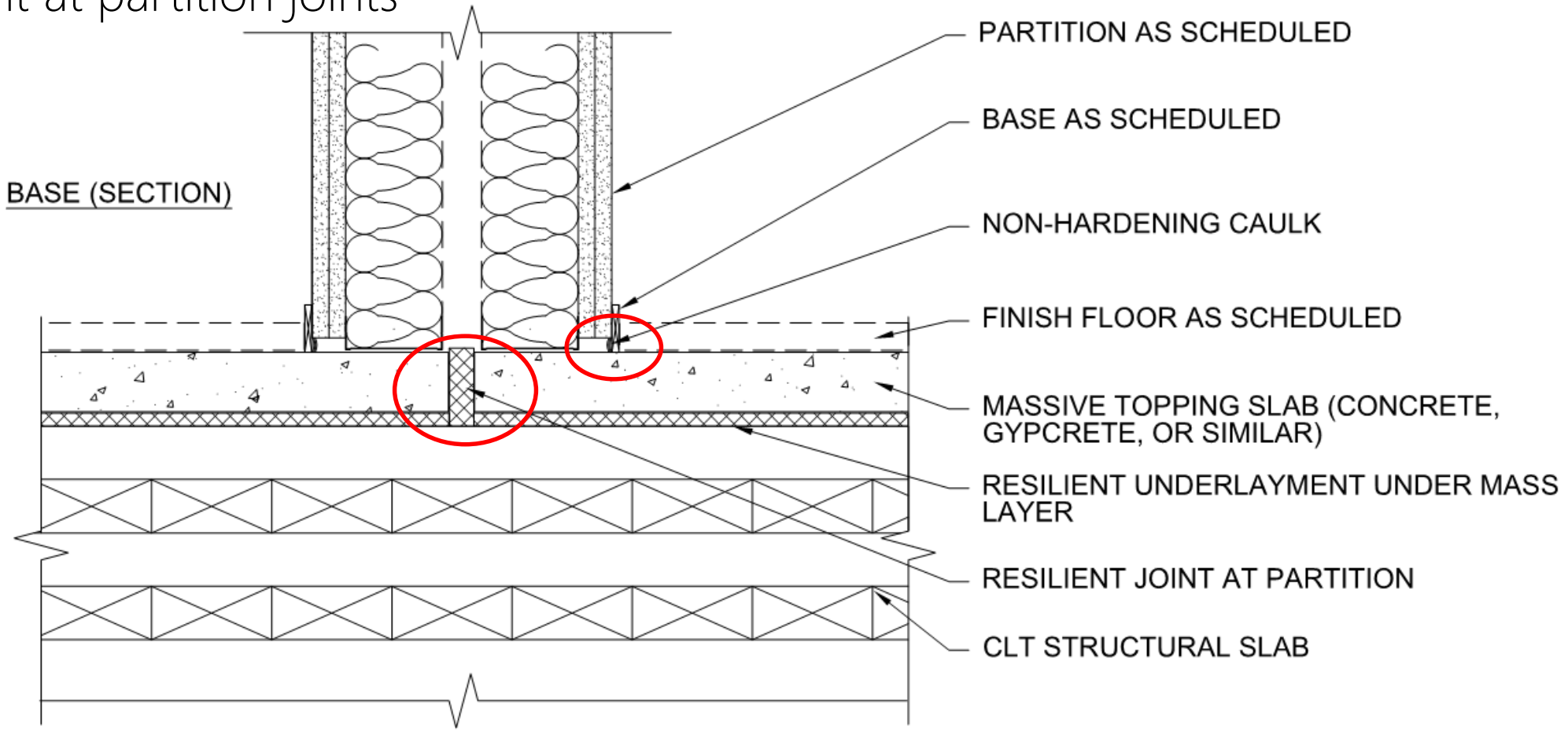
Sound source

Flanking Noise Considerations



Flanking Control

- Decoupling of floor screed from CLT
- Decoupling walls from space below
- Acoustic sealant at partition joints

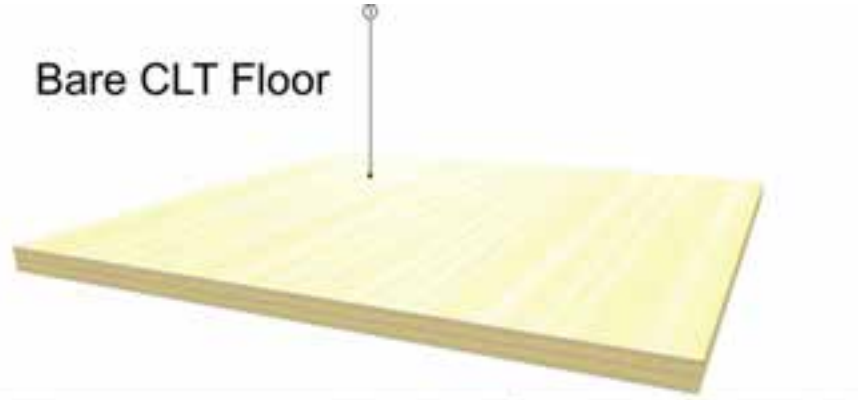


Selection of Assemblies

CLT without “acoustic covering”

Sketch and Short Description	STC Rating	IIC Rating
 Bare CLT 5 ply (175 mm)	42	26

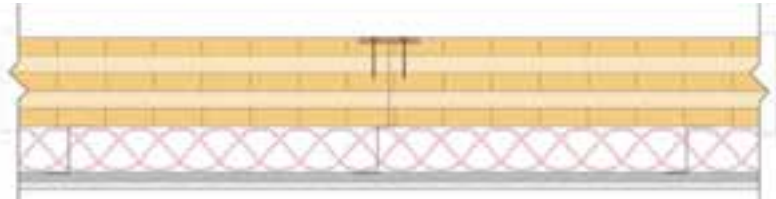
Sketch and Short Description	STC Rating	IIC Rating
 Bare CLT 5 ply (131 mm)	39	22

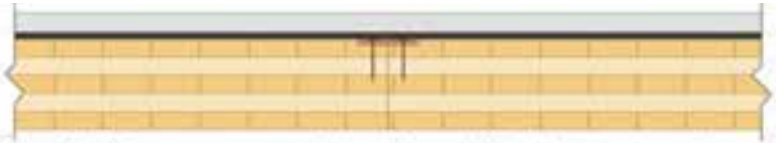


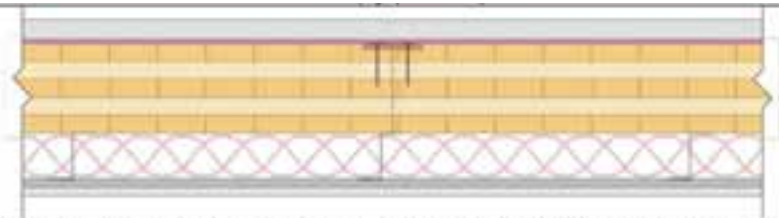
Floor Composition	Airborne (STC) dB	Impact (IIC) dB
5-layer CLT panel 146 mm	39	24

CLT with different “acoustic coverings”

Sketch and Short Description	STC Rating	IIC Rating
 Bare CLT 5 ply (175 mm)	42	26

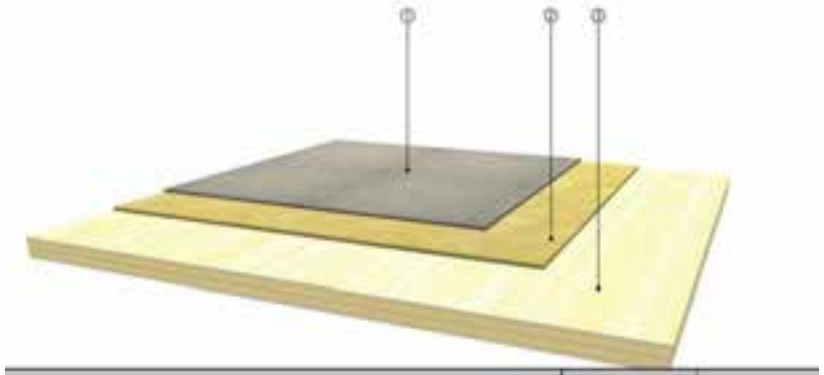
Sketch and Short Description	STC Rating	IIC Rating
 CLT 5 ply (175 mm) with one layer of 16 mm Type X gypsum board installed on Z channels	62	48

Sketch and Short Description	STC Rating	IIC Rating
 38 mm (1-1/2") precast concrete slab on 13 mm (1/2") rubber membrane placed on top of a CLT 5 ply (175 mm).	56	48

Sketch and Short Description	STC Rating	IIC Rating
 38 mm (1-1/2") precast concrete slab on 9 mm closed cell foam placed on top of a CLT 5 ply (175 mm) with one layer of 16 mm Type X gypsum board installed on Z channels.	70	56

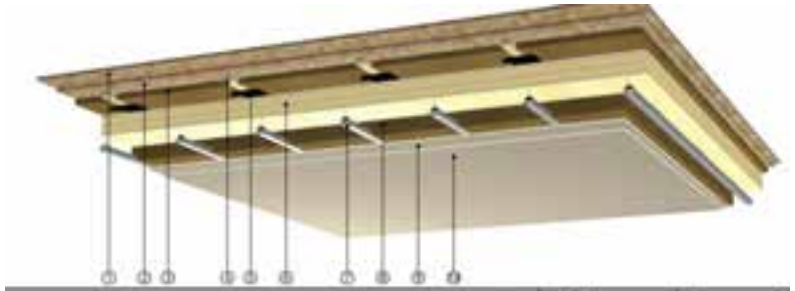
CLT floor assemblies

Floor Composition	Airborne (STC) dB	Impact (IIC) dB
5-layer CLT panel 146 mm	39	24



	Floor Composition	Airborne (STC) dB	Impact (IIC) dB
1	Gypsum fibre board FERMACELL 25 mm	≤ 53	≤ 49
2	Sub-floor ISOVER EP3 20 mm		
3	5-layer CLT panel 135 mm		

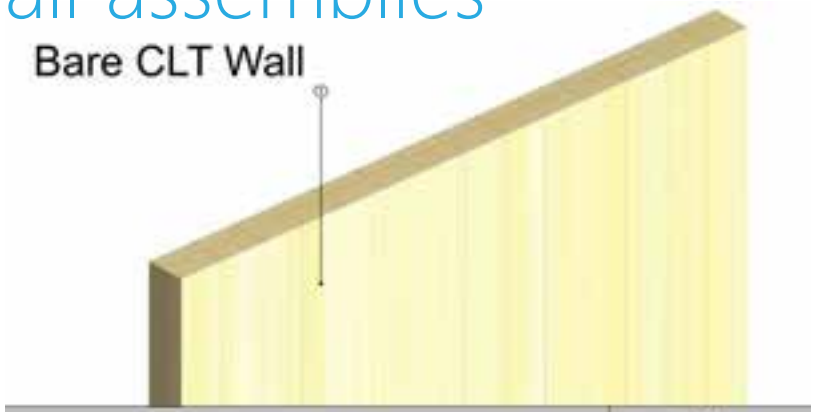
	Floor Composition	Airborne (STC) dB	Impact (IIC) dB
1	5-layer CLT panel 146 mm	64	59
2	Resilient supports and rails (100 mm)		
3	Sound insulation material (100 mm)		
4	Gypsum board 13 mm		
5	Gypsum board 13 mm		



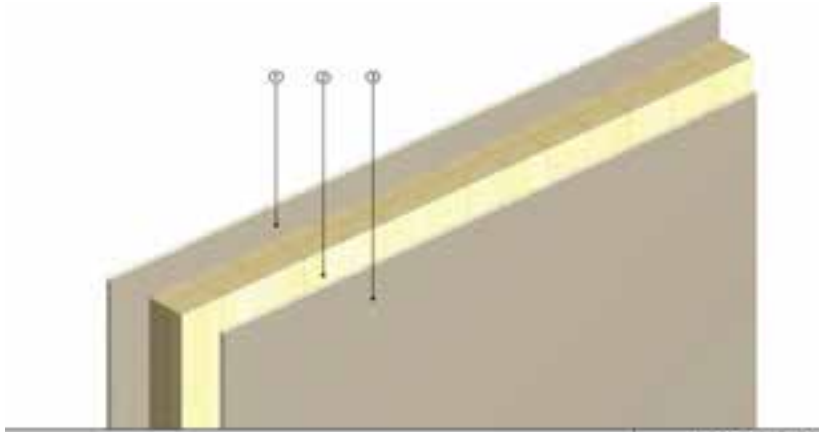
	Floor Composition	Airborne (STC) dB	Impact (IIC) dB
1	Particleboard panel 22 mm	67	≥ 62
2	Particleboard panel 22 mm		
3	Sound insulation material (≈ 40 mm)		
4	Lumber sleepers		
5	REGUPOL underlayment		
6	5-layer CLT panel 146 mm		
7	Resilient supports and rails (100 mm)		
8	Sound insulation material (100 mm)		
9	Gypsum board 13 mm		
10	Gypsum board 13 mm		

CLT wall assemblies

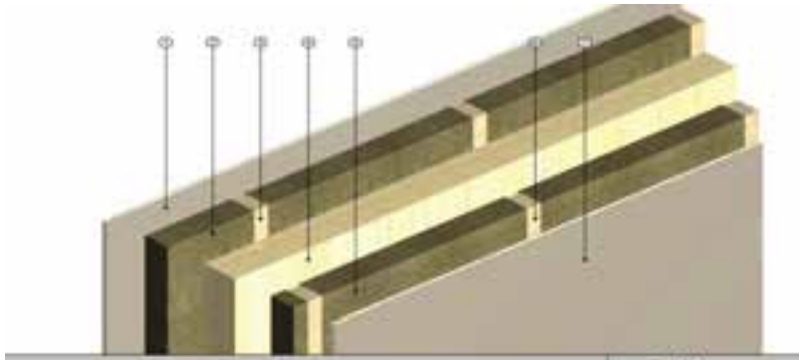
Bare CLT Wall



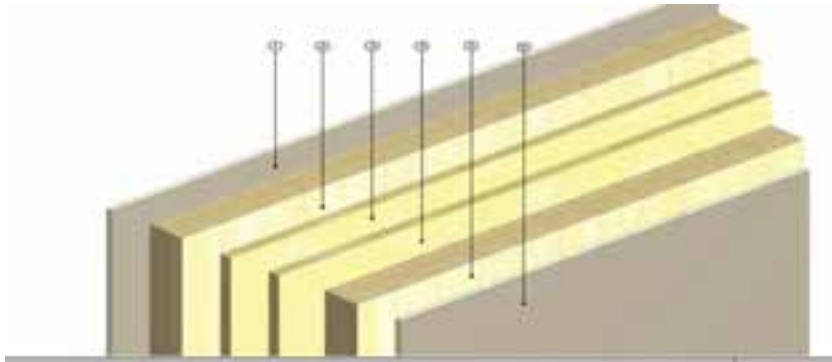
	Wall Composition	Airborne (STC) dB
1	3-layer CLT panel (95 mm ~ 115 mm)	≤ 32~34



	Wall Composition	Airborne (STC) dB
1	Gypsum board 15 mm	≤ 36~38
2	3-layer CLT panel (95 mm ~ 115 mm)	
3	Gypsum board 15 mm	



	Wall Composition	Airborne (STC) dB
1	Gypsum board 15 mm	≤ 58
2	Mineral wool (~ 60 mm)	
3	Lumber studs (38 mm x 63 mm)	
4	3-layer CLT panel (95 mm ~ 115 mm)	
5	Mineral wool (~ 60 mm)	
6	Lumber studs (38 mm x 63 mm)	
7	Gypsum board 15 mm	

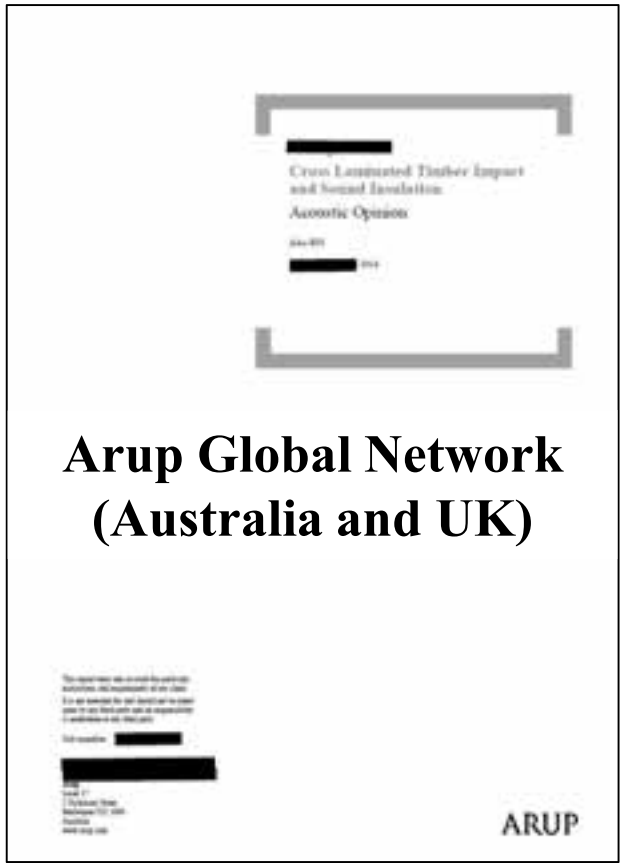


	Wall Composition	Airborne (STC) dB
1	Gypsum board 15 mm	≤ 60
2	3-layer CLT panel (95 mm ~ 115 mm)	
3	Sound insulation material (rock wool) (~ 30 mm)	
4	Sound insulation material (rock wool) (~ 30 mm)	
5	3-layer CLT panel (95 mm ~ 115 mm)	
6	Gypsum board 15 mm	

Technical Resources

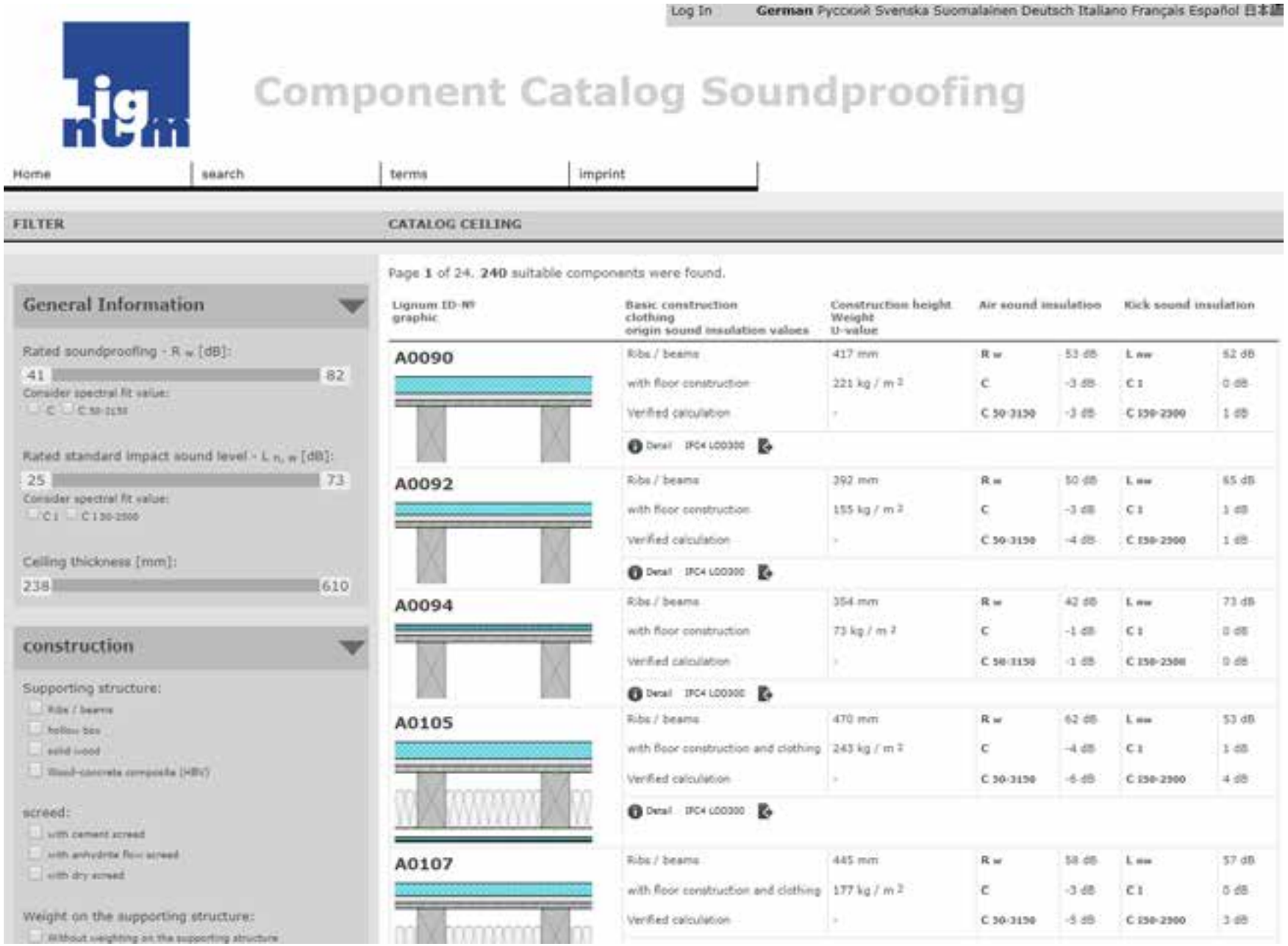
Industry Publications

Research Publications



Arup Global Network (Australia and UK)

Building Regulations in other countries (UK, etc)

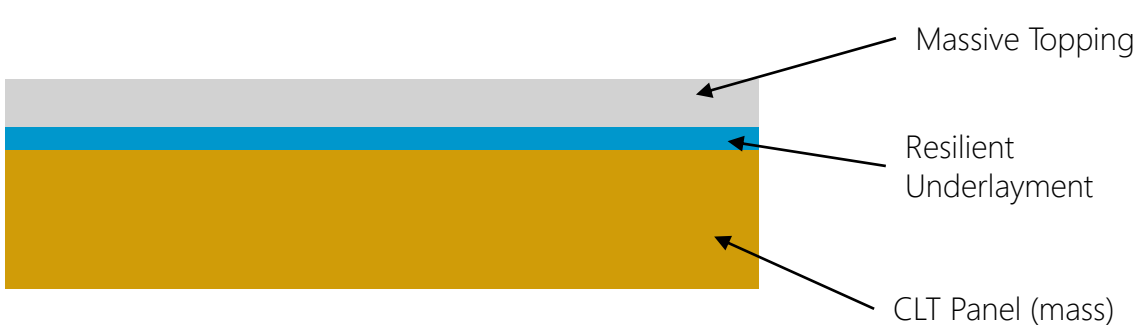


https://lignumdata.ch/

Case Study #1:
Modular Multifamily Prototype Study with Katerra

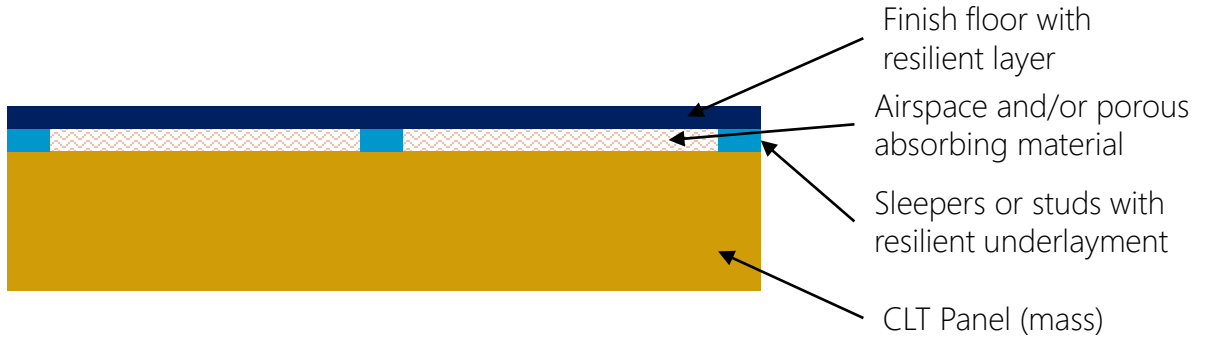
Acoustic Design Concepts

Single Panel Acoustic Concept Sketch



- Construction: CLT panel base topped with a resiliently isolated mass
- Airborne Isolation: relies on adding mass until STC rating is achieved (typically concrete), and does not have the benefit of an airspace.
- Impact Isolation: relies on impedance mismatch and decoupling caused by a thin resilient underlayment layer between the CLT and the topping.

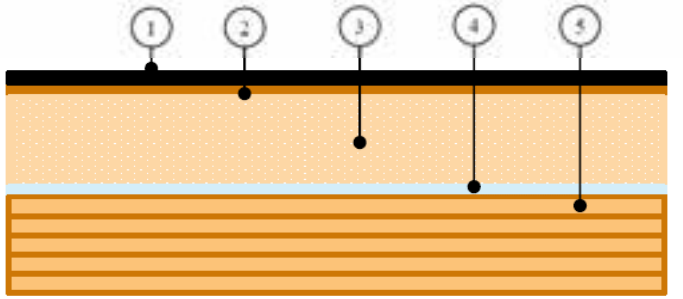
Double Panel Acoustic Concept Sketch



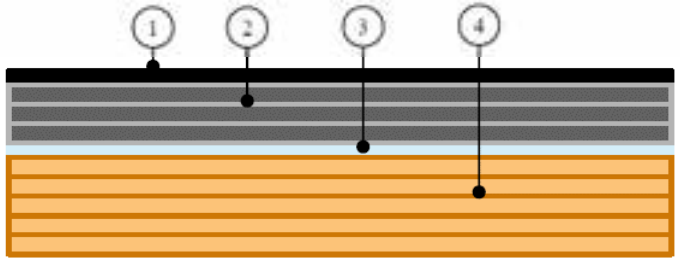
- Construction: Finish material and backer affixed to the CLT panel base by sleepers or studs across an airspace filled with sound absorbing material.
- Airborne Isolation: Relies on absorption from a porous absorbing material and the size of the airspace
- Impact Isolation: Relies on decoupling of finish material and backers from the CLT panel

Preliminary Design Options

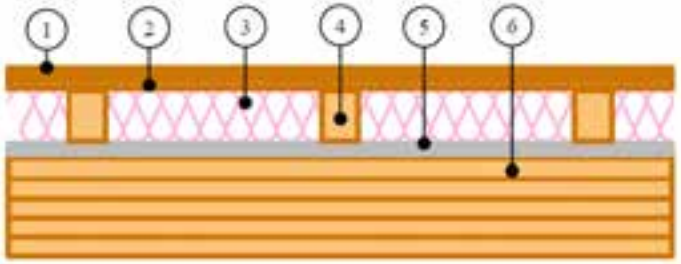
1. CLT with massive sand topping



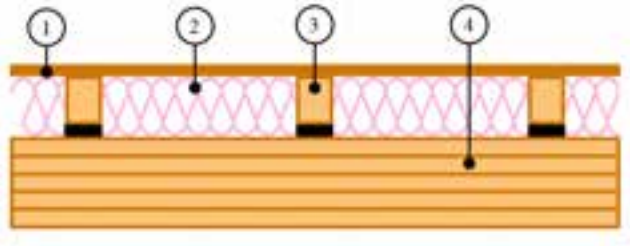
2. CLT with cement board topping



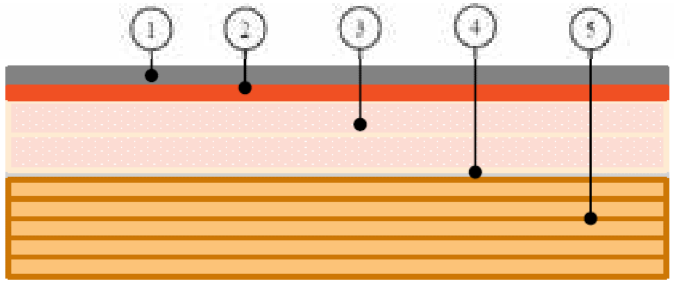
3. Resilient sleepers



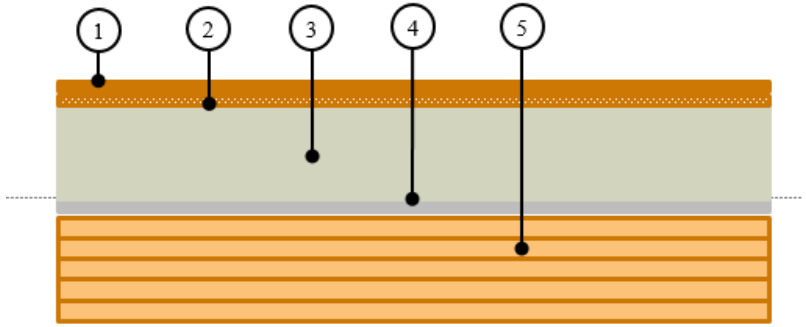
4. InstaCoustic Acoustic Batten option



5. Fermacell honeycomb option



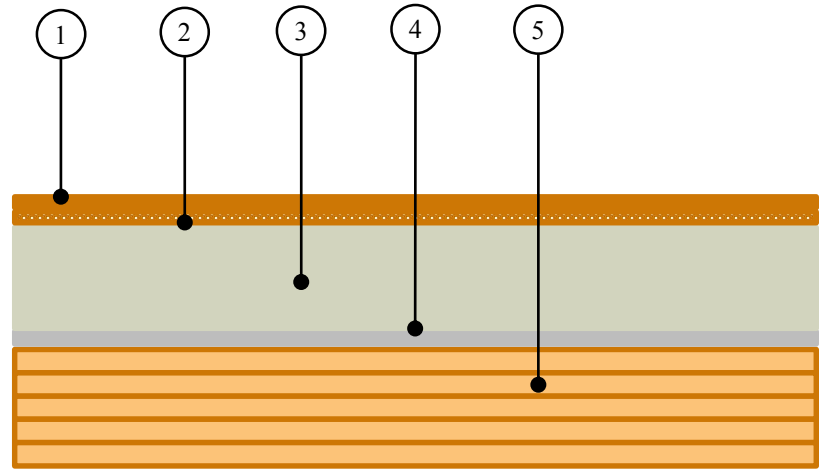
6. Absorptive Solid Concept



Preferred Design Option

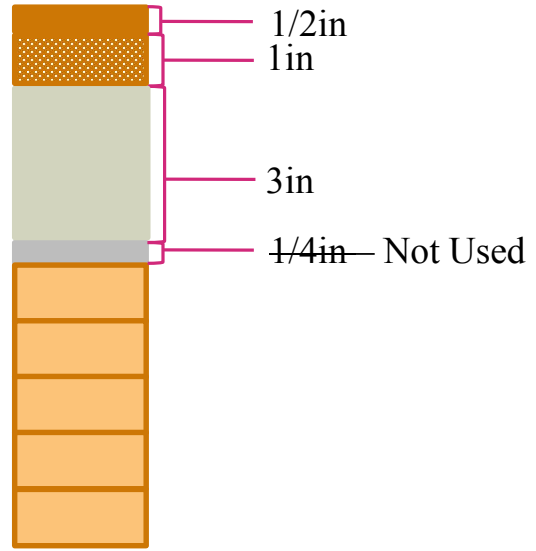
“Absorptive Solid” Concept (design and prediction by Arup)

1. 1/2in plywood (~1.5psf)
2. 1in Particleboard panel* (~4.25psf)
3. 3in mineral wool (~3.125psf)
4. ~~Resilient underlayment (~1.5psf~~) – Not Used
5. 5-layer CLT assembly (~ 1.3625in per layer)



STC	IIC
~45*	~44*

Total Topping Depth (in)	Total Topping PSF
~4.75	~10.4



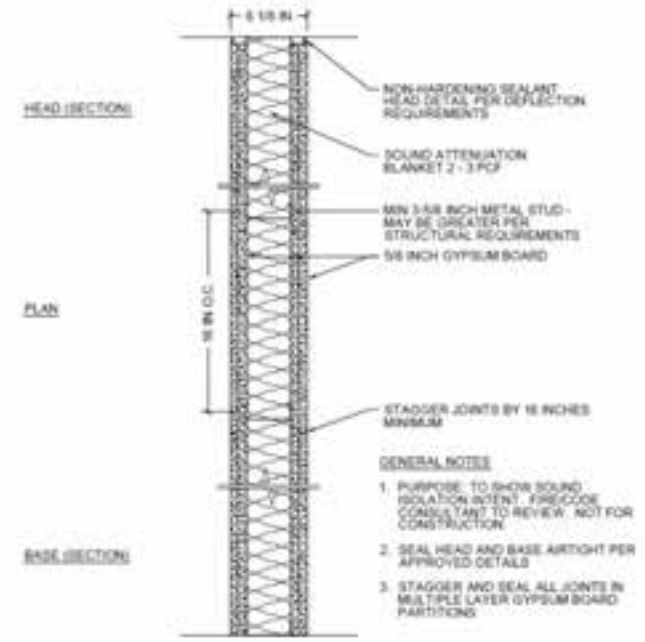
*While this construction does not meet the IBC requirements, the addition of a resilient floor finish (e.g. carpet) and/or additional mass layers should improve the performance of the IIC and STC within “striking distance” of STC and IIC 50. Modeling and testing of similar floor constructions suggests that IIC 50 is attainable depending on the selected floor finish.

Preferred Design Option for Prototype Testing

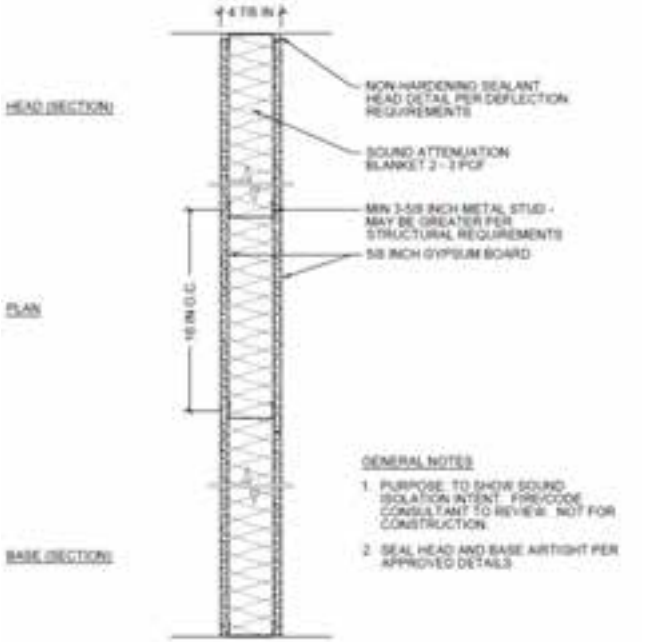
Wall/Ceiling Requirements for Acoustic Tests

In order to ensure that the test specimen is measured accurately, the building elements supporting and surrounding the floor must meet minimum acoustic isolation requirements. The diagram below indicates the required level of isolation and example constructions of the elements not under test.

1. Structural slab or testing site floor slab – No acoustic requirements
2. Receiving Room walls – STC 55 or greater
3. Floor assembly under test
4. Source Room walls – STC 45 or greater (demountable)
5. Source Room ceiling – STC 45 or greater (demountable)

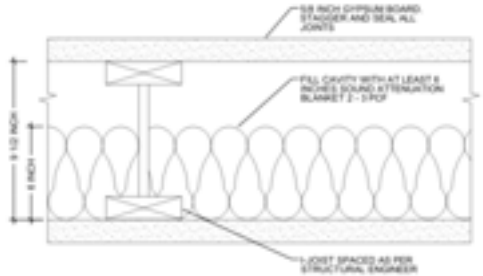


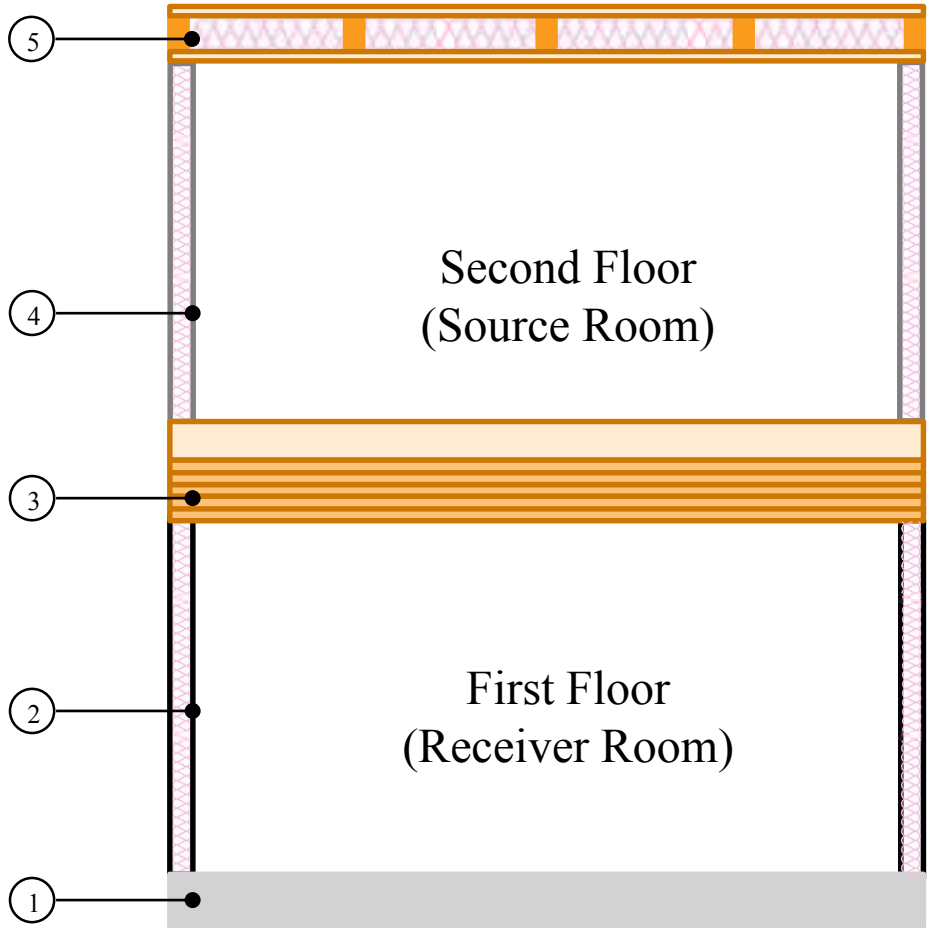
STC 55 partition sketch detail



STC 45 partition sketch detail

STC 45 ceiling sketch detail





Scope of the Measurements

On June 12th – 14th, 2017, we conducted acoustic tests at the Katerra Site to measure the following:

1. Airborne sound isolation of mass timber floor assemblies per *ASTM E336: Standard Test Method for Measurement of Airborne Sound Insulation in Buildings*
2. Impact sound isolation of mass timber floor assemblies per *ASTM E1007: Standard Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling Assemblies and Associated Support Structures*
3. The low frequency (50-250 Hz) airborne and impact sound isolation of floor assemblies not included in *ASTM E336 and ASTM 1007*
4. Determination of structural dynamic characteristics and measurement response to footfall induced vibration.

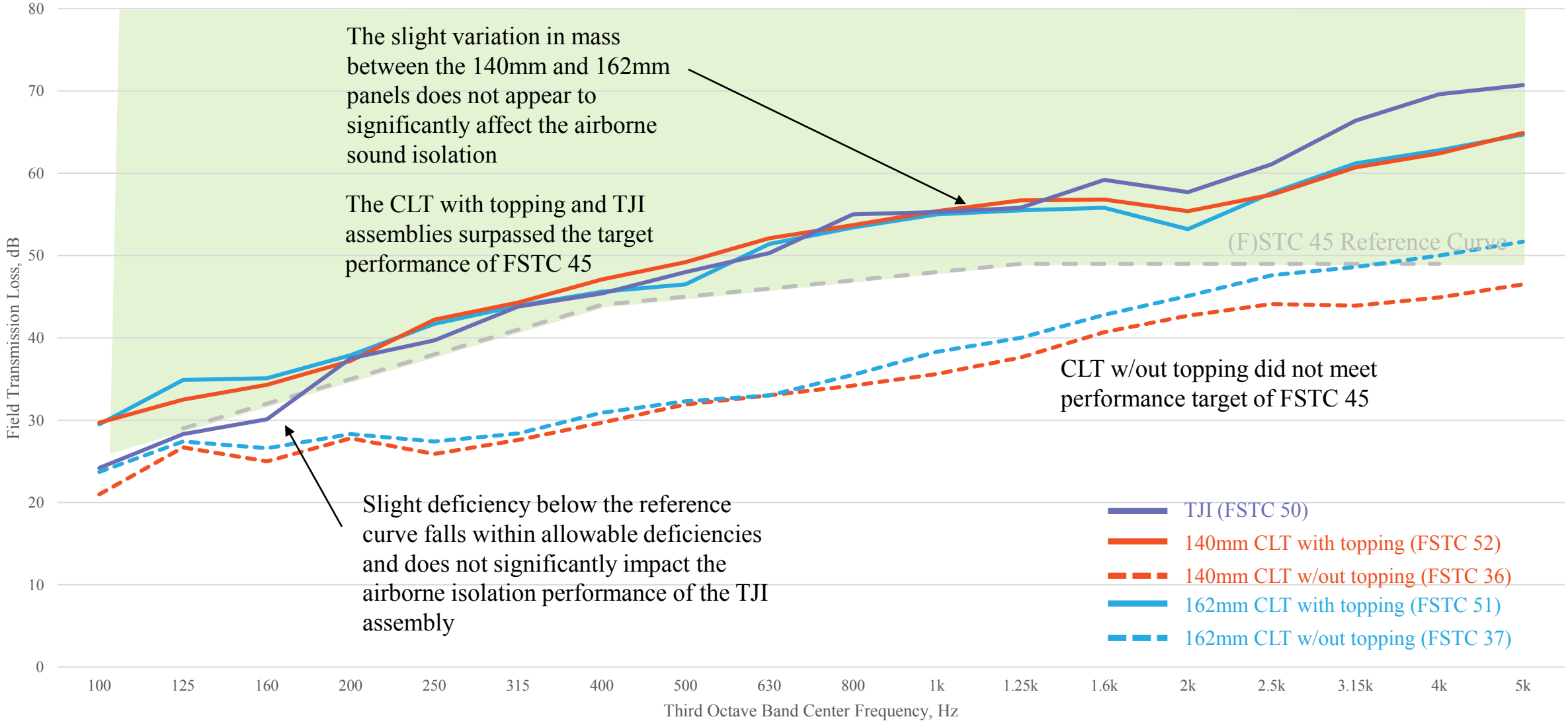
Impact sound testing

Airborne sound testing

Vibration Testing

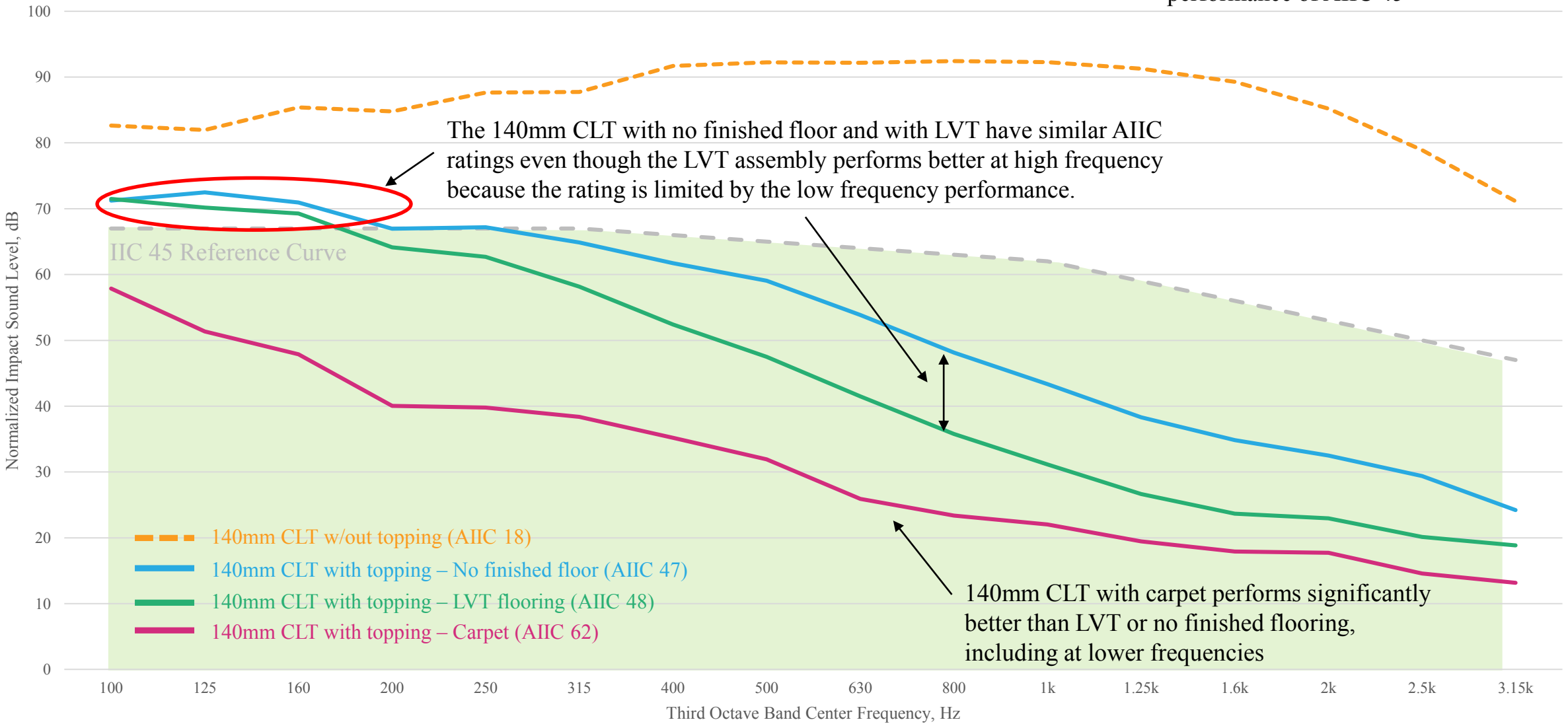
Acoustic Testing Results

Airborne Sound Isolation Results (FSTC)

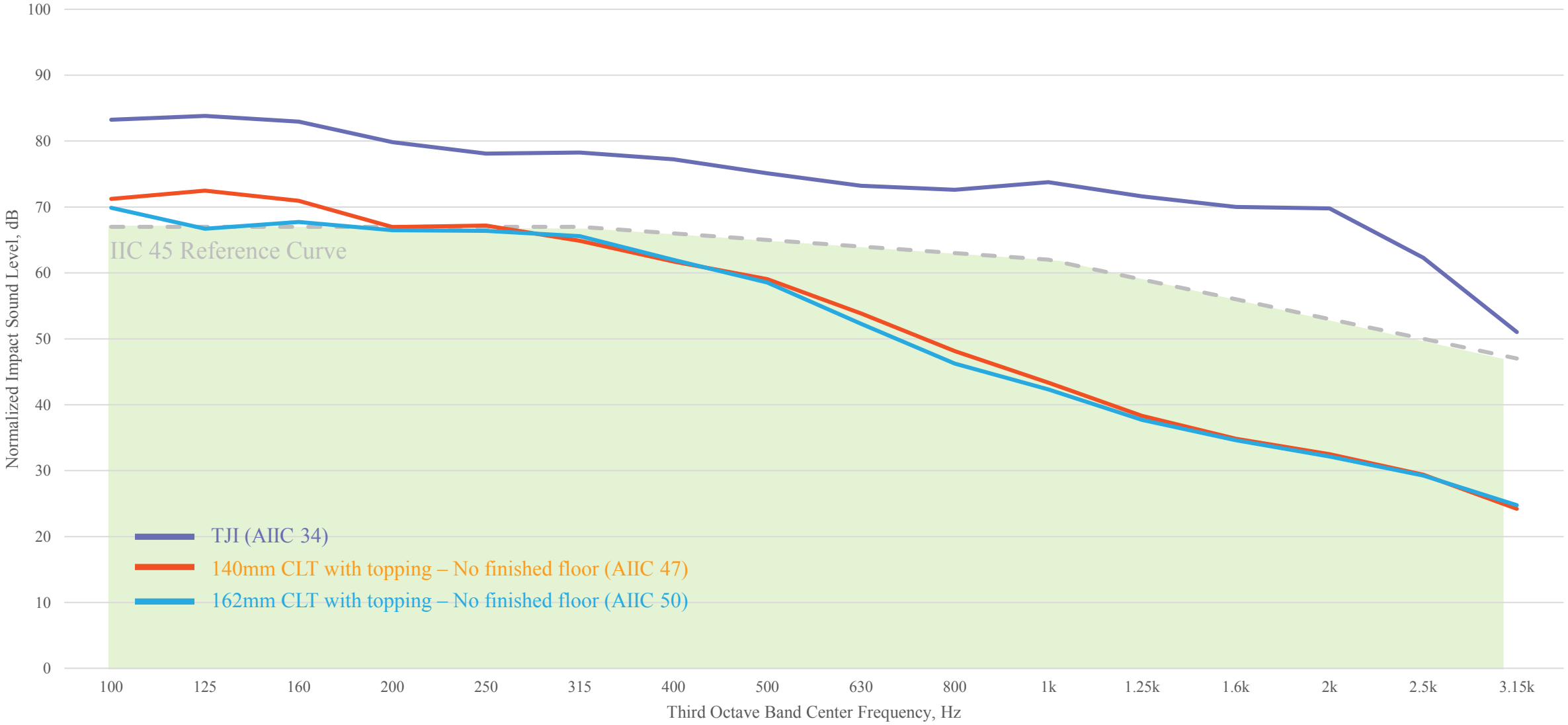


Impact Sound Level Results (140mm CLT)

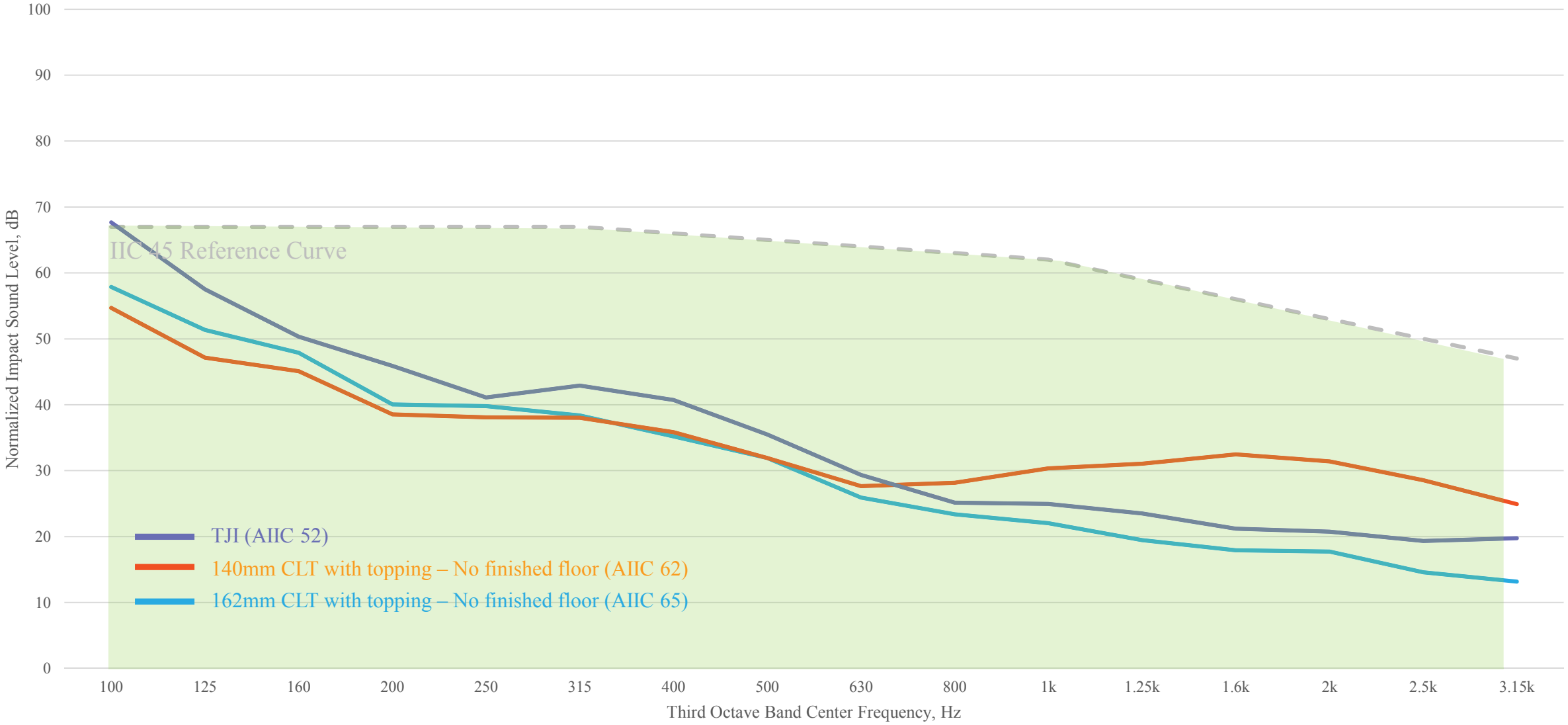
All tested assemblies except the 140mm CLT w/out a topping surpassed the target performance of AIIC 45



Impact Sound Level Results – No Finished Floors



Impact Sound Level Results – Carpet



Ongoing Research

1. Establishing new baselines for the subjective performance of mass timber constructions

2. Innovative "acoustic covering" designs
   - Implications for fire/structure?
   - Elimination of wet trades to allow for manufacturing efficiency?

3. Leveraging CLT as a finish
   - Hone viable floor/ceiling/wall assemblies to expose wood as a finish

"HAUT" w/ Team V Architecture

Architecture is Acoustics,
Acoustics is Architecture

"...'Total Architecture' implies that all relevant design decisions have been considered together and have been integrated into a whole..."

Sir Ove Arup
Key Speech,1970

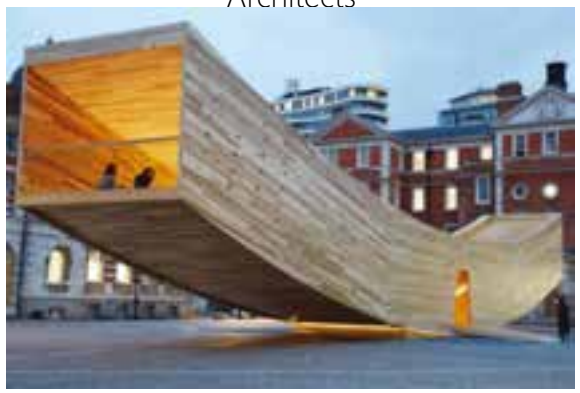
Arup and Mass Timber

Low2No – Sauerbruch Hutton Architects

NMIT Nelson – Irving Smith Jack Architects

Framework – Lever Architecture

Bellevue First Congregational Church – atelier jones



The Smile - AHEC

Thank you

This concludes The American Institute of Architects Continuing Education Systems Course

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ARUP