Forskningsprosjekt Woodsol: akustikk i fleretasjes trebygg

Simone Conta
NTNU, Institutt for bygg- og miljøteknikk

NAS Høstmøte 2019,
Trondheim, 26. oktober 2019

NTNU WOODSOL

Min bakgrunn

- BSc in Applied Physics fra universitetet i Trento (Italia)
- MSc in Engineering Acoustics fra DTU (Danmark)
- 9 års erfaring som akustikk rådgiver hos Müller-BBM GmbH (Tyskland)

- PhD stipendiat hos NTNU siden april 2017 (Veileder: Anders Homb)

WOODSOL

Vibroacoustic analysis of the Woodsol timber frame building concept

Outline

- The WOODSOL project
- Acoustic goals and strategy
- Insight in the methods
- Sample results
- Summary

Context

THE WOODSOL PROJECT

Woodsol

- Funded by the Norwegian Research Council
- Budget 36.4 mill NOK where 30.6 from NRC
- Timeframe 2016 - 2019

- NTNU
- SINTEF

- Project leader: Kjell Arne Malo (NTNU)

WOODSOL motivation

- Open architecture (bracing, span)

Mjøstårnet, Brumenddal, 80 m

Photo: Moelven press material

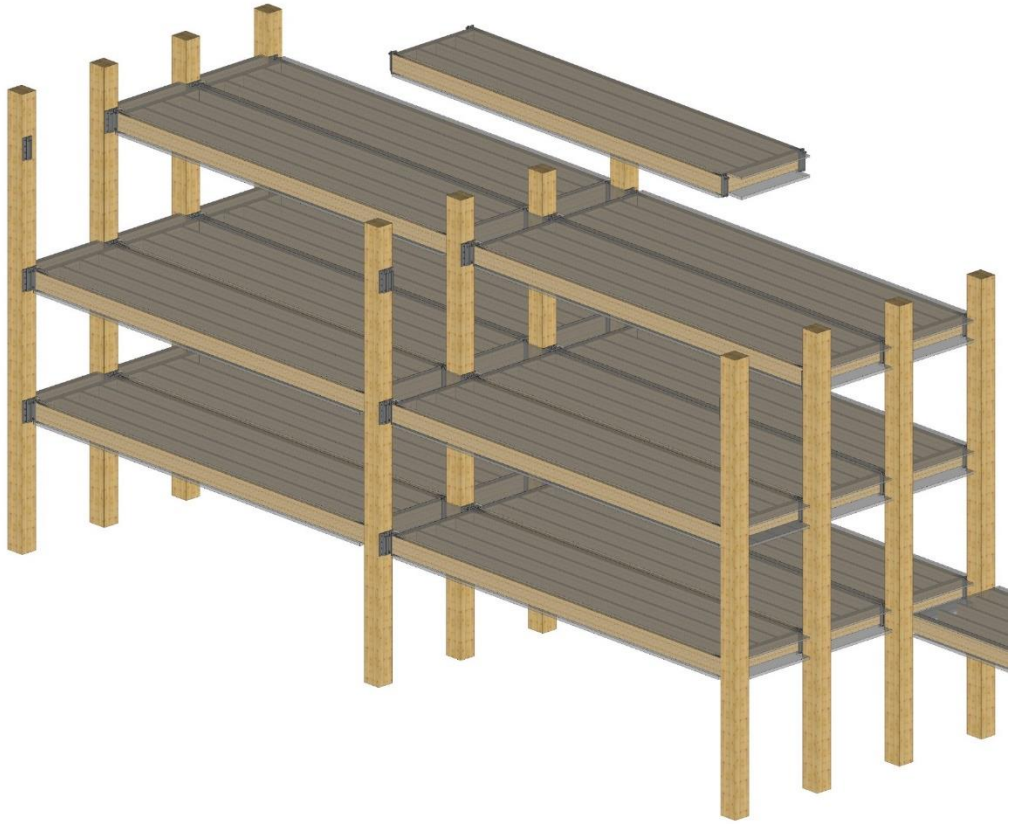
Treet, Bergen, 49 m

Photo from: https://aeworldmap.com/2017/04/03/30880/

Tall wood residence, Vancouver, 53 m

Photo: Pollux Chung /courtesy of Seagate Structures
From: https://www.detail-online.com/article/18-floors-in-wood-student-residence-in-vancouver-30362/

WOODSOL concept



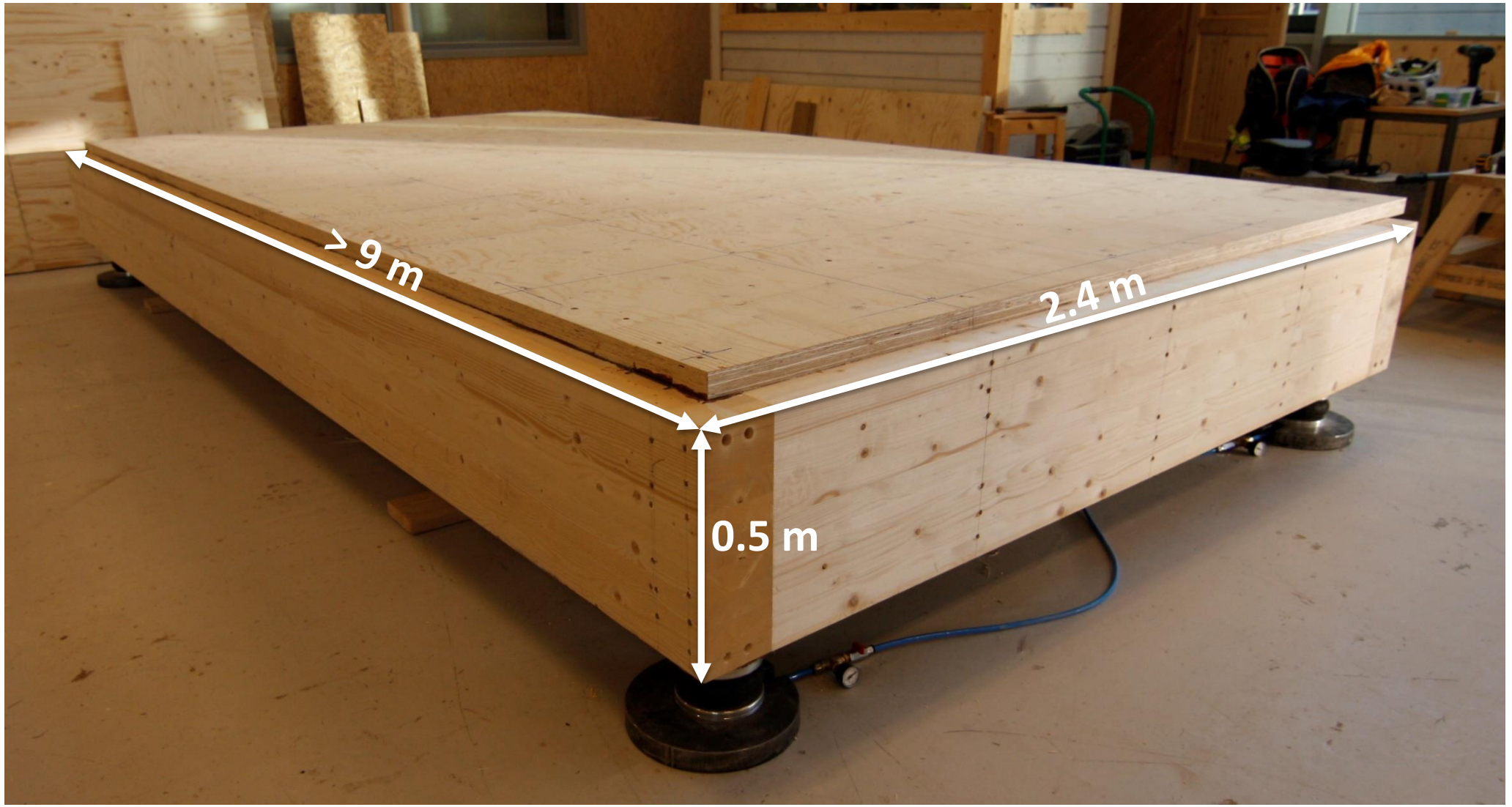
Three substantial targets need to be accomplished to reach the main goal:

1. **The extension of the floor span length without increased storey height.**
2. **The horizontal stabilization of the building by moment resisting frames.**
3. **The development of prefabricated couplings to allow rapid erection on site.**

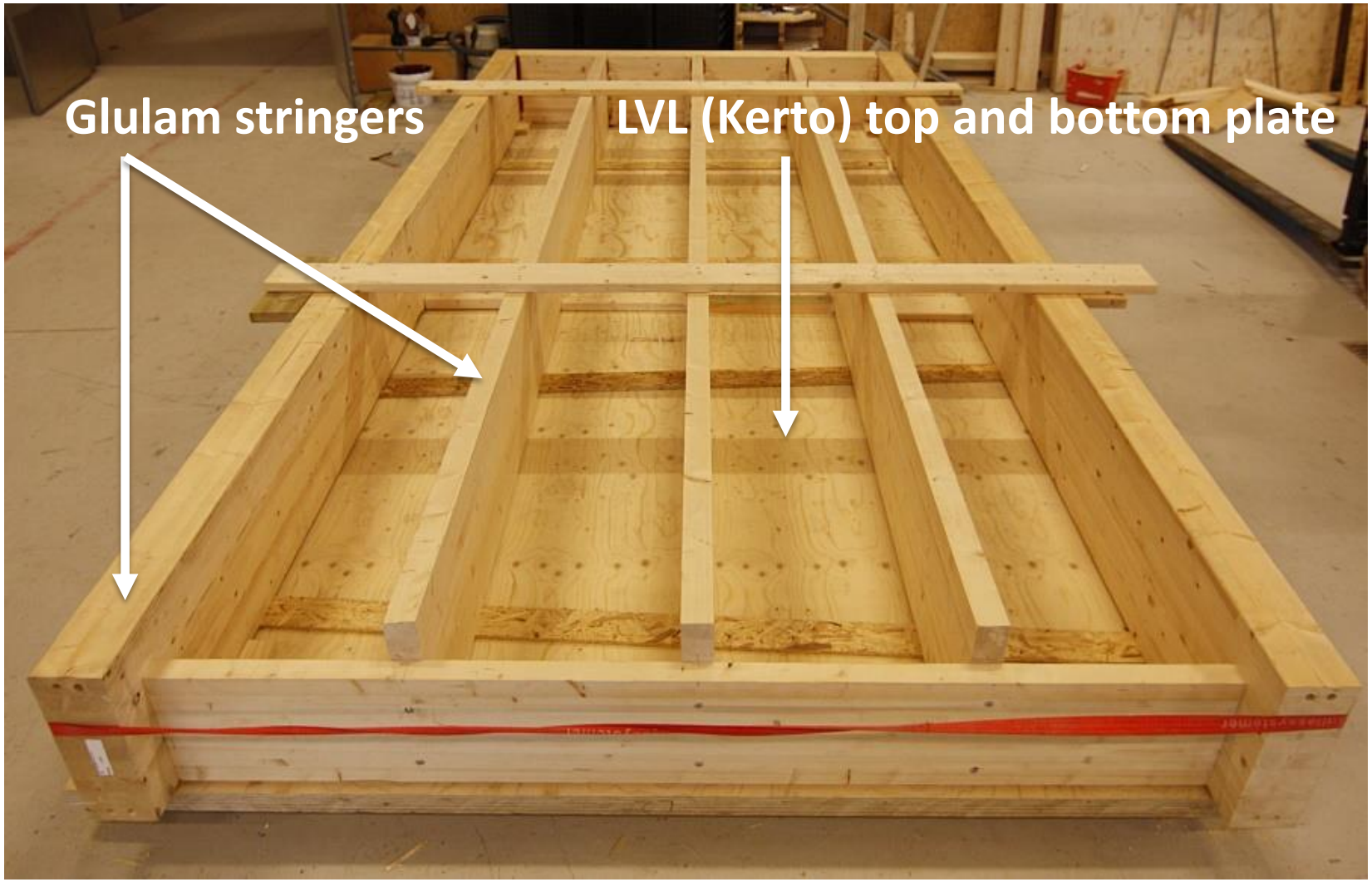
Woodsol focuses on four main subjects:

- **Production and assembly of structural systems and component**
- **Moment resisting frames**
- **Flooring systems**
- **Acoustics**

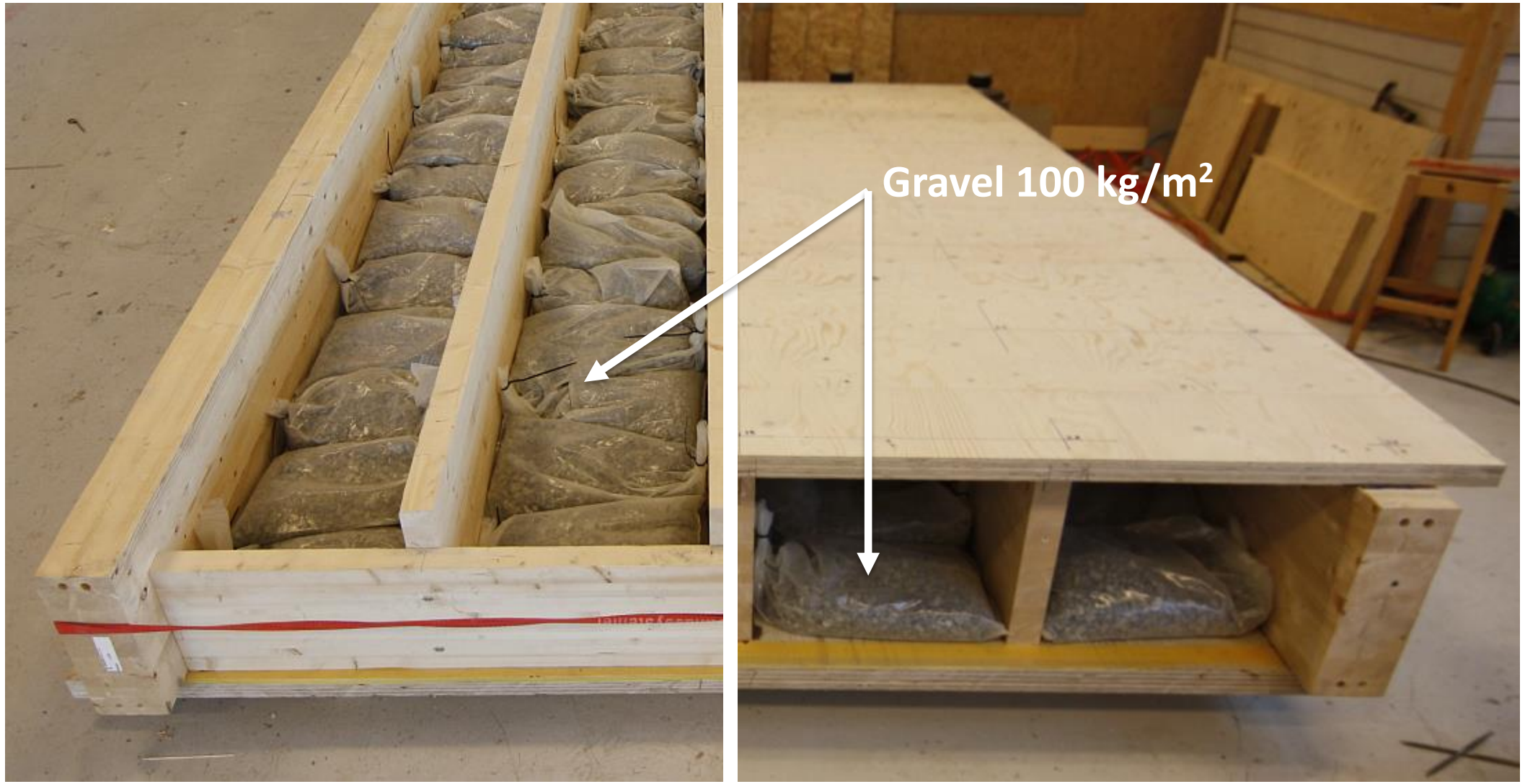
WOODSOL floor element



WOODSOL floor element

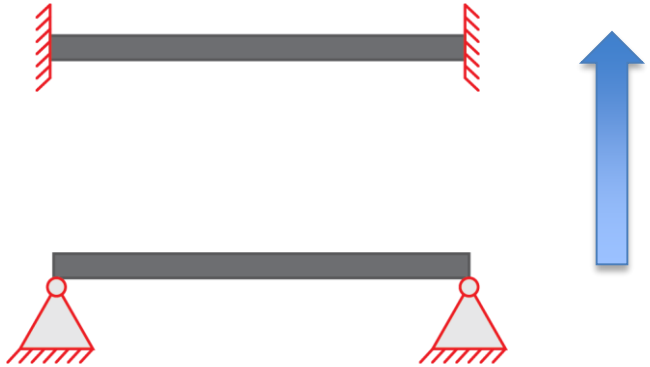


WOODSOL floor element



Moment resisiting connection

- Long span (> 9 m)

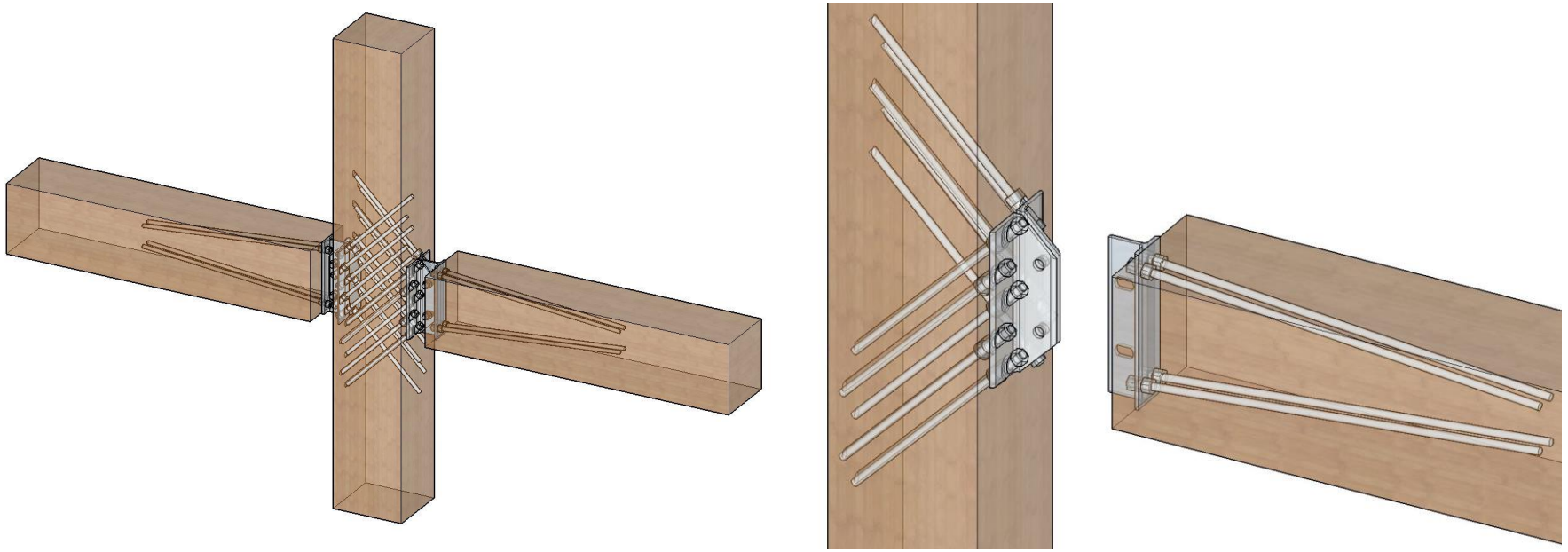


Span (first natural frequency) increases

Malo, K.A. and J. Köhler. *Vibrations of timber floor beams with end restraints. in Structures and Architecture: Concepts, Applications and Challenges–Proceedings of the 2nd International Conference on Structures and Architecture, ICSA. 2013. CRC Press.*

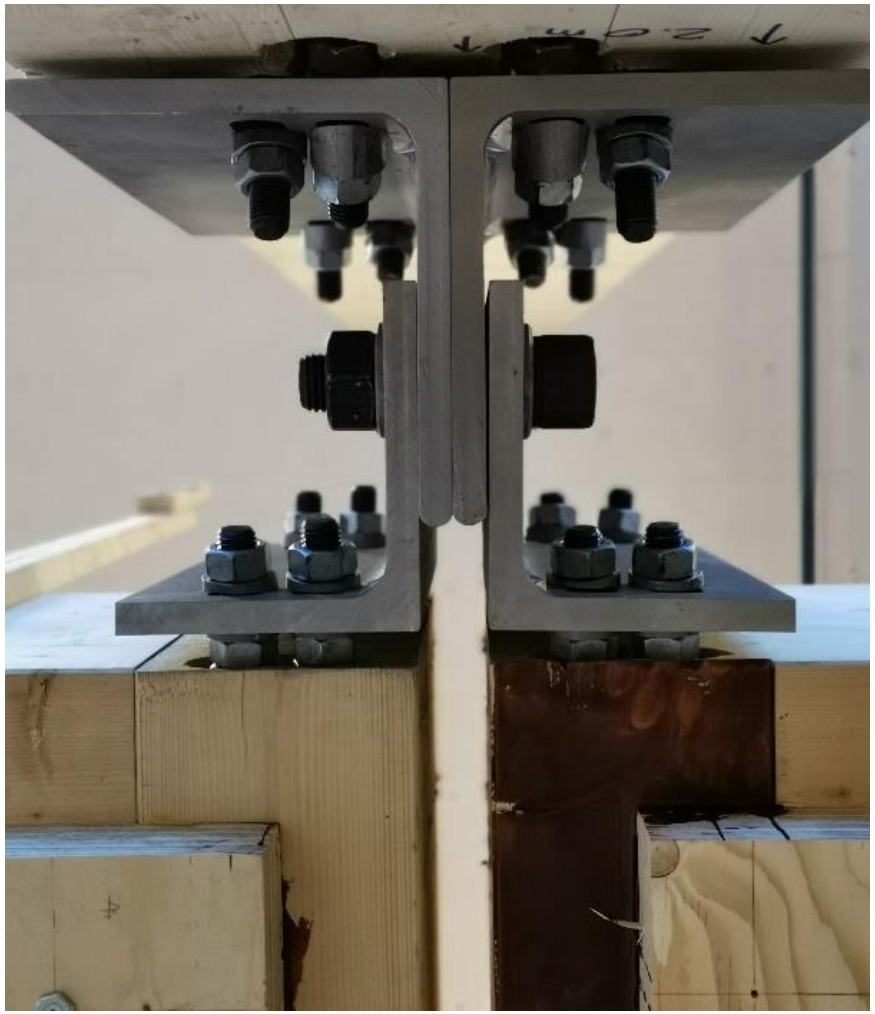
WOODSOL connector

- Aiming at a rotational stiffness: $K_\theta \approx 8000$ ..13500 kNm/rad



Vilguts A, Malo KA, Stamatopoulos H. *Moment resisting frames and connections using threaded rods in beam–to-column timber joints.* WCTE; Seoul2018

WOODSOL connector

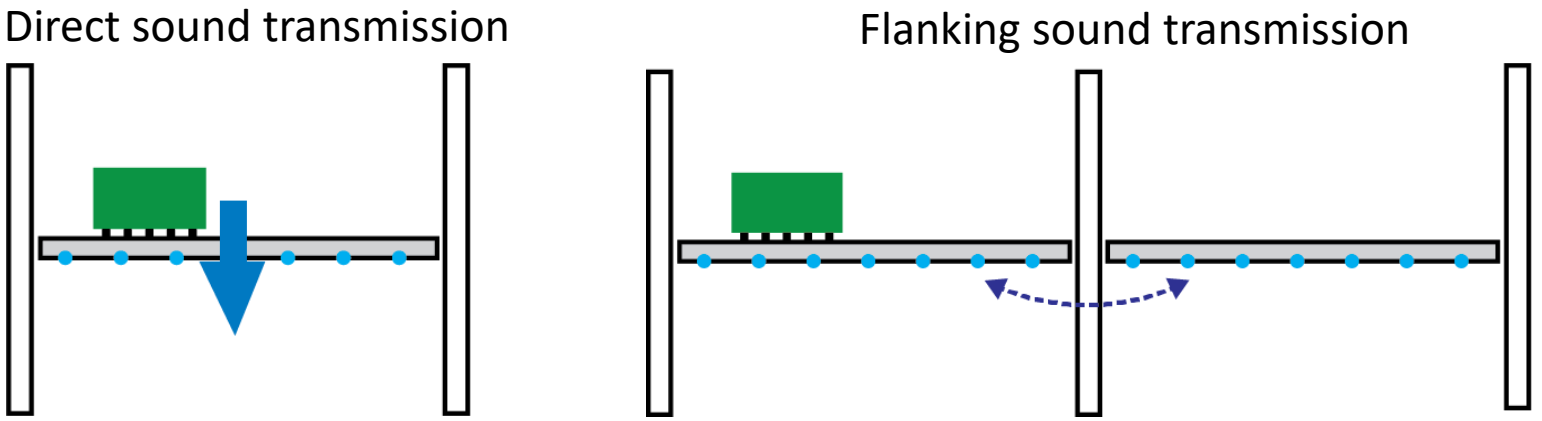


WOODSOL prototype

ACOUSTIC IN WOODSOL

WOODSOL acoustic tasks

- Assessment and design of sound insulation (Focus: impact noise)



- Challenges: low frequency (20 Hz – 100 Hz), span (9 m), connectors

Vibro-acoustic assessment strategy

I: Experimental modal analysis, EMA

II: Integral Transform Method, ITM

III: Junction Transmission measurements, JTM

Homb, A., Conta,S., **Strategies to evaluate acoustic properties of timber hollow box floors**, Internoise 2019, Madrid, June 16-19, 2019

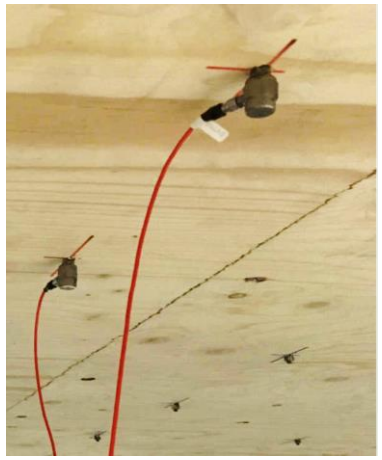
Vibro-acoustic assessment strategy (1)

EXPERIMENTAL MODAL ANALYSIS

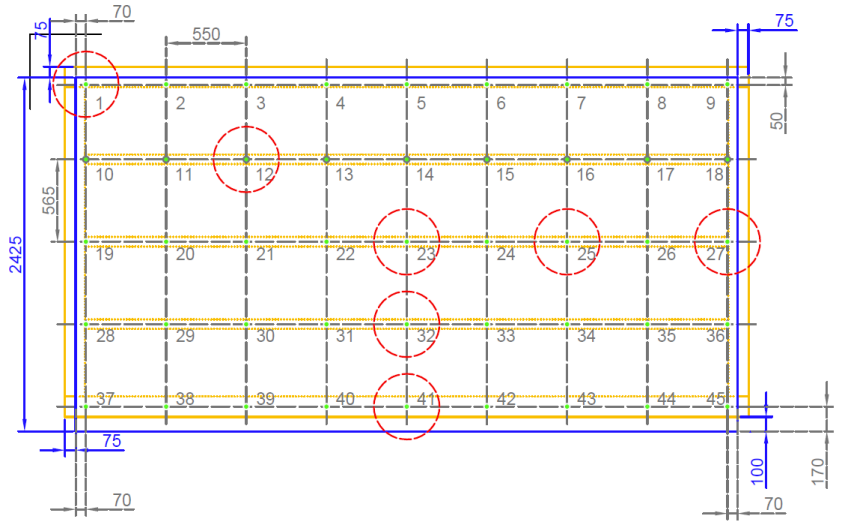
Experimental modal analysis, EMA

- Investigate vibrational modes
- Tool to validate numerical models

Source: modal hammer



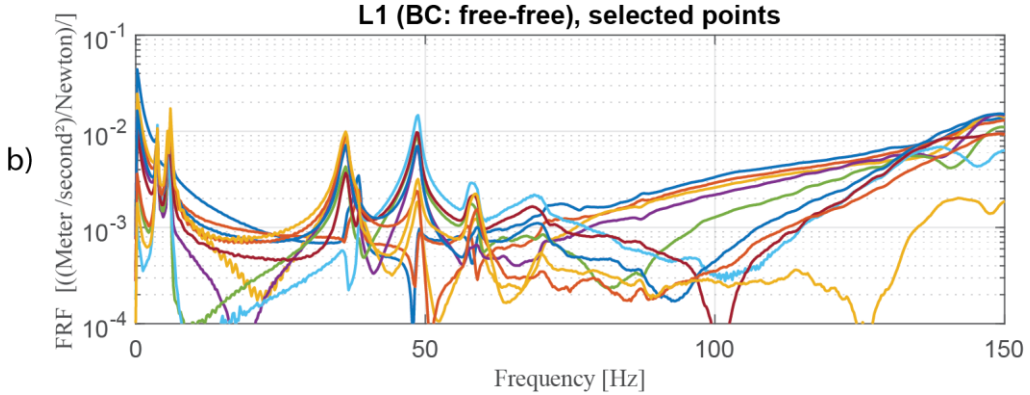
Receiver: accelerometer



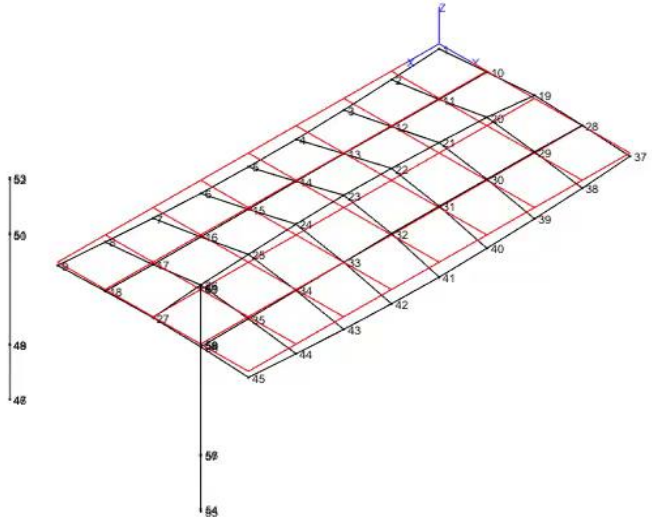
Measurement grid 50 cm x 50 cm

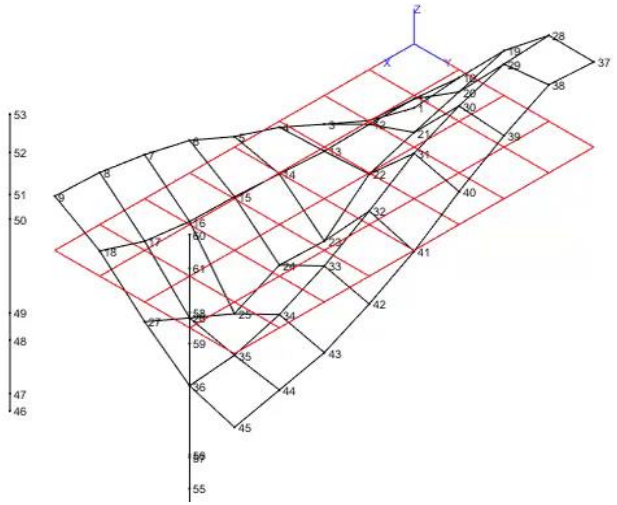
EMA results

Transfer function
Acceleration/force



Vibration modes ~40 Hz



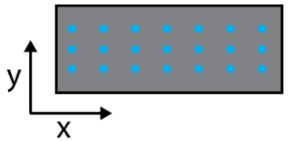


Vibro-acoustic assessment strategy (2)

INTEGRAL TRANSFORM METHOD

The integral transform method

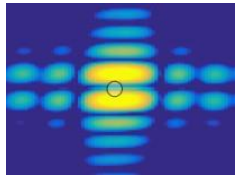
STEP 1: Measure the vibration velocity



$$\hat{v}(x, k, f)$$

- Grid size!!

STEP 2: Transform to the wavenumber domain



$$\hat{v}(k_x, k_y, f)$$

- 2D Fourier transform (Grid size!!)
- Zero padding…

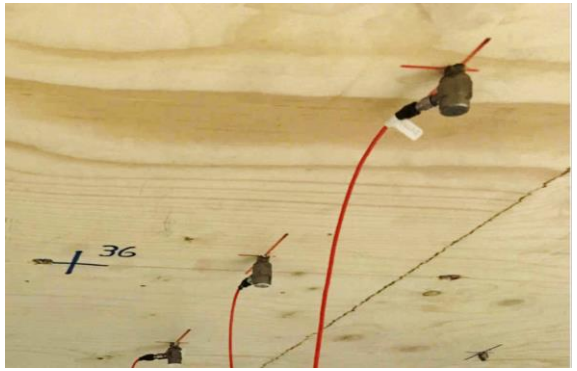
STEP 3: Calculate radiated sound power with following relation

$$P[\gamma] = \frac{1}{2}\frac{\rho_A c_A}{4\pi^2}\Re\left[\sum_{\alpha=1}^{M_\alpha}\sum_{\beta=1}^{M_\beta} K[\alpha,\beta,\gamma]\cdot|\hat{v}[\alpha,\beta,\gamma]|^2\Delta x^2\Delta y^2\right]\Delta k_x \Delta k_y$$

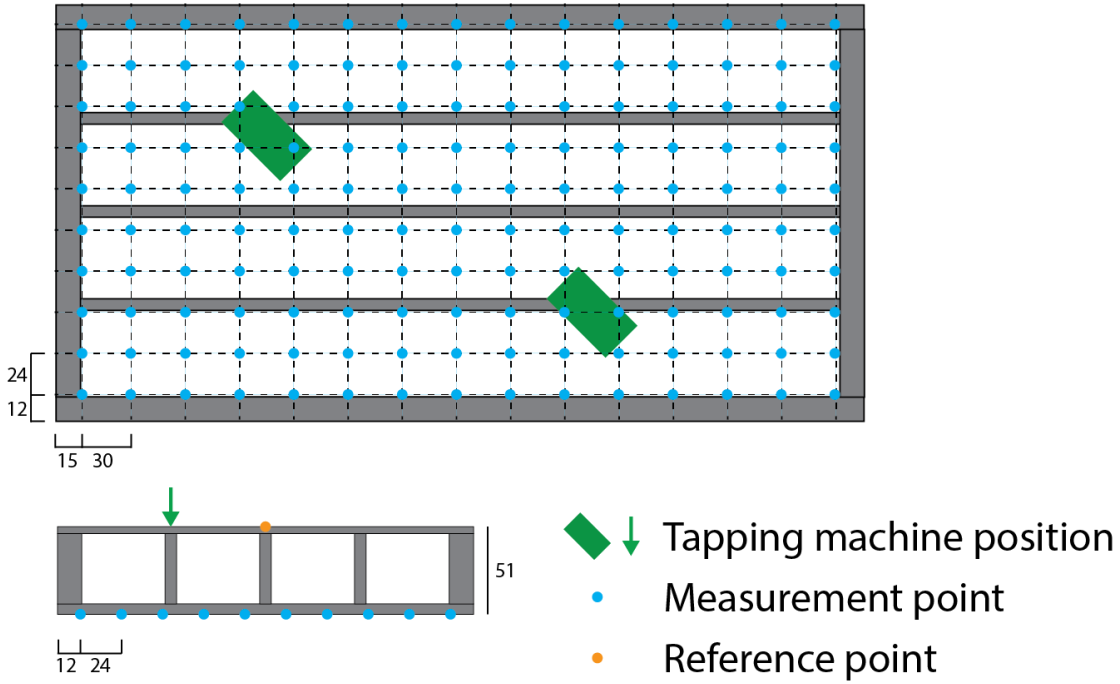
ITM Step 1: measure vibration velocity

- Assessment of direct sound transmission

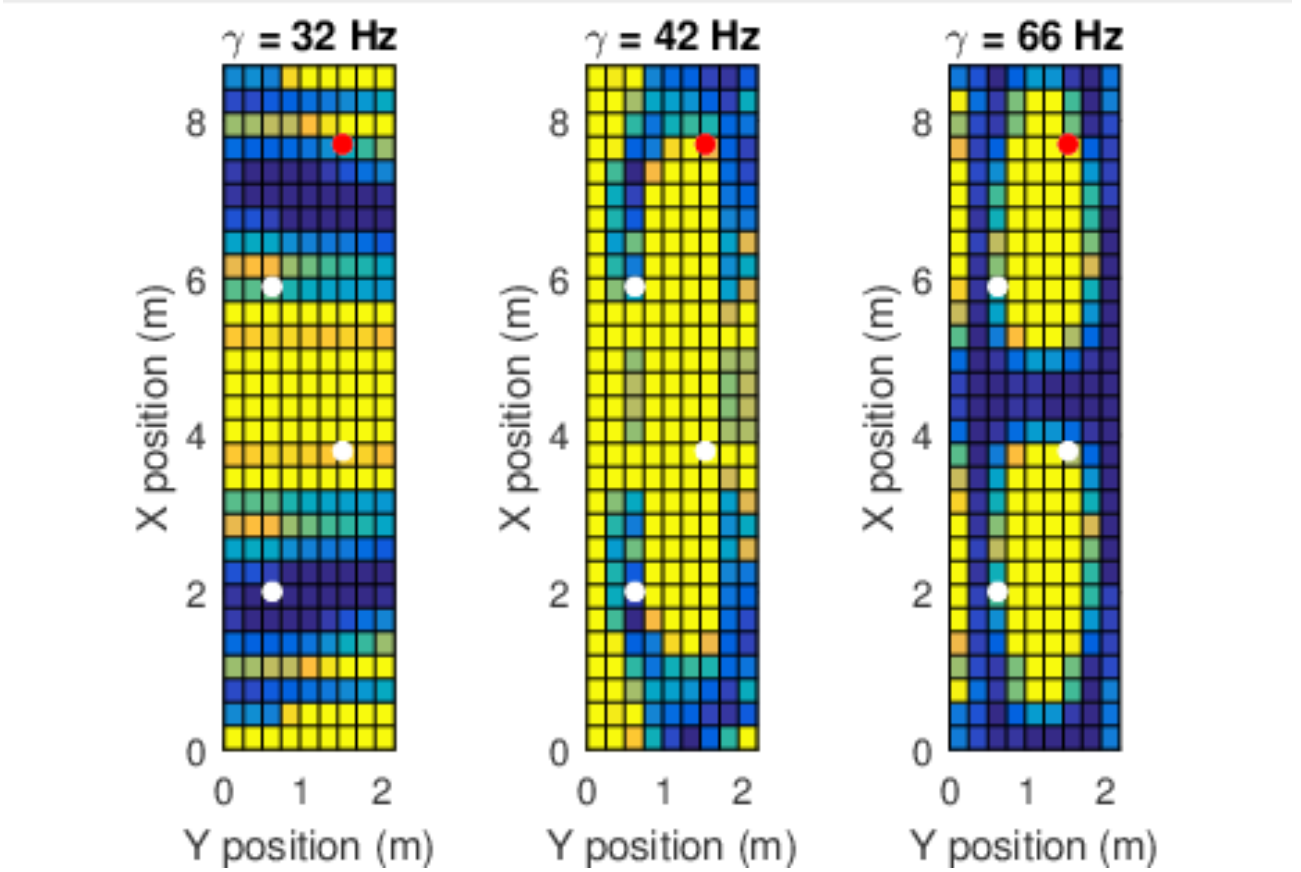
Source: standard tapping machine



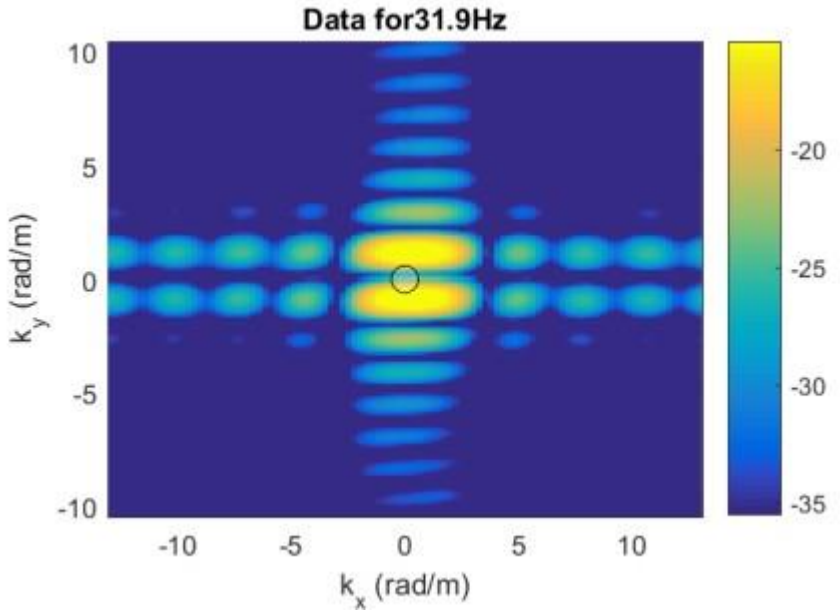
Receiver: accelerometers

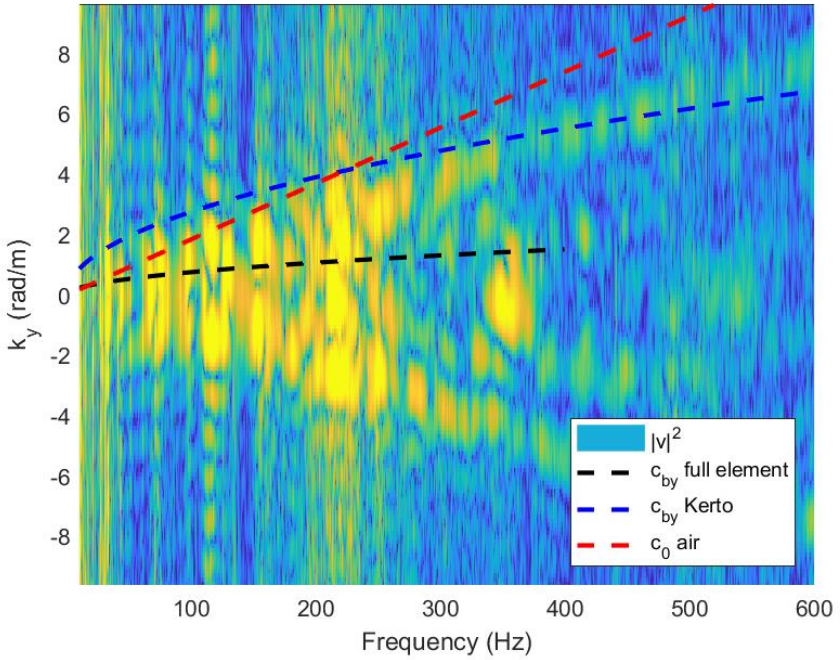


Measured vibration velocity

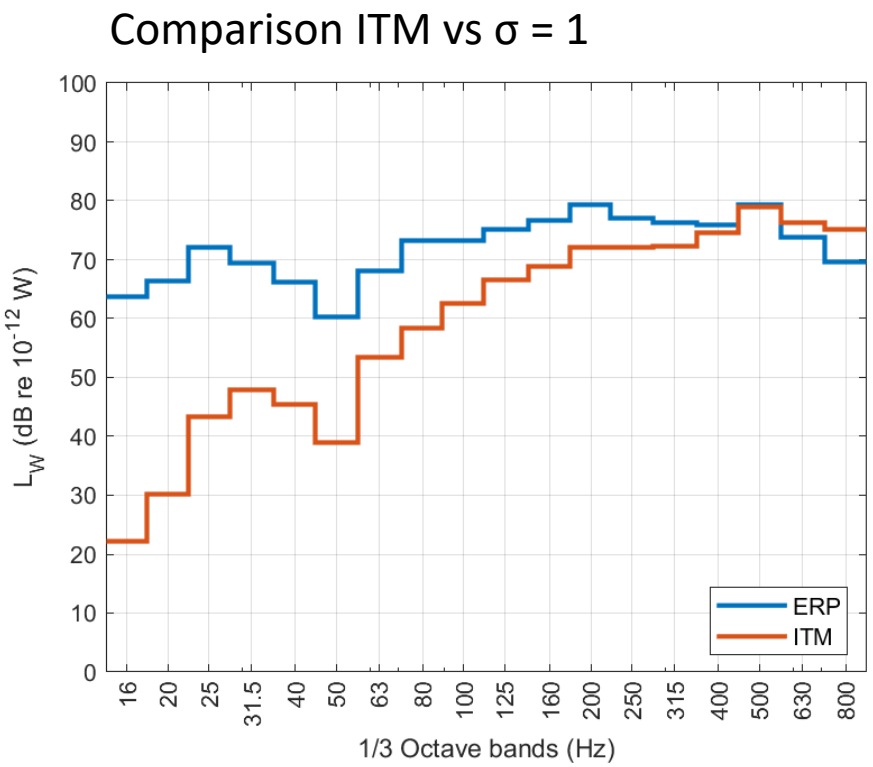


ITM Step 2: convert to wavenumber domain



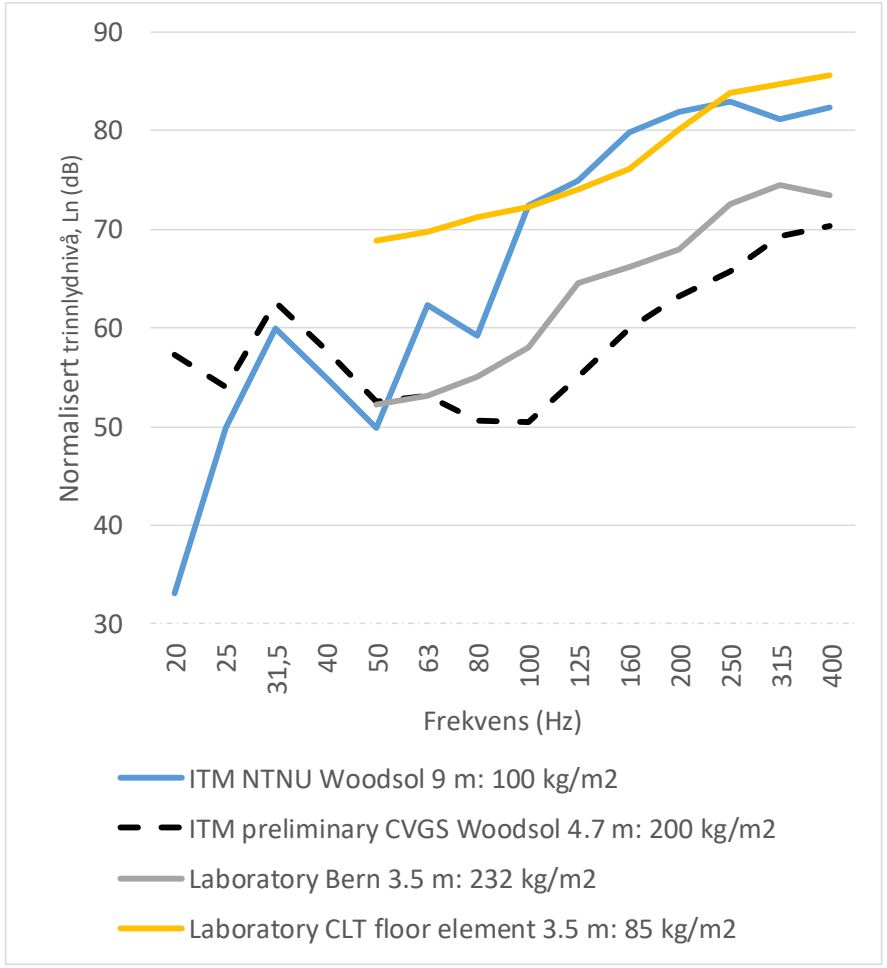


ITM Step 3: calculate radiated sound power



Impact noise level

- Span: 9m, 4.7 m
- Gravel: 0 or ~ 100 kg/m2
- ITM vs standard laboratory measurements



From: Homb, A., Conta,S., **Strategies to evaluate acoustic properties of timber hollow box floors**, Internoise 2019, Madrid, June 16-19, 2019

ITM advantages

- Acoustic lab is not required
- It is possible to perform measurements on
  - Full size objects*
  - With the correct boundary conditions*

} Critical at frequencies below 150 Hz

- Results:
  - Radiated sound power
  - Impact noise level
  - Radiation factor σ

Conta, S., Homb, A., **Challenges and limitations using the Integral Transform Method to obtain the impactnoise level of timber floors**, in Proceedings of Euronoise 2018, M. Taroudakis (Ed.), Crete, May 27-31, 2018(pp.: 667-674), SSN: 2226-5147. (publisert)

Conta S., Homb A., Sound radiation of hollow box timber floors under impact excitation: an experimental parameter study, submitted for publication to Applied Acoustics, Elsevier (under review)

Investigate effect of additional mass

Without gravel

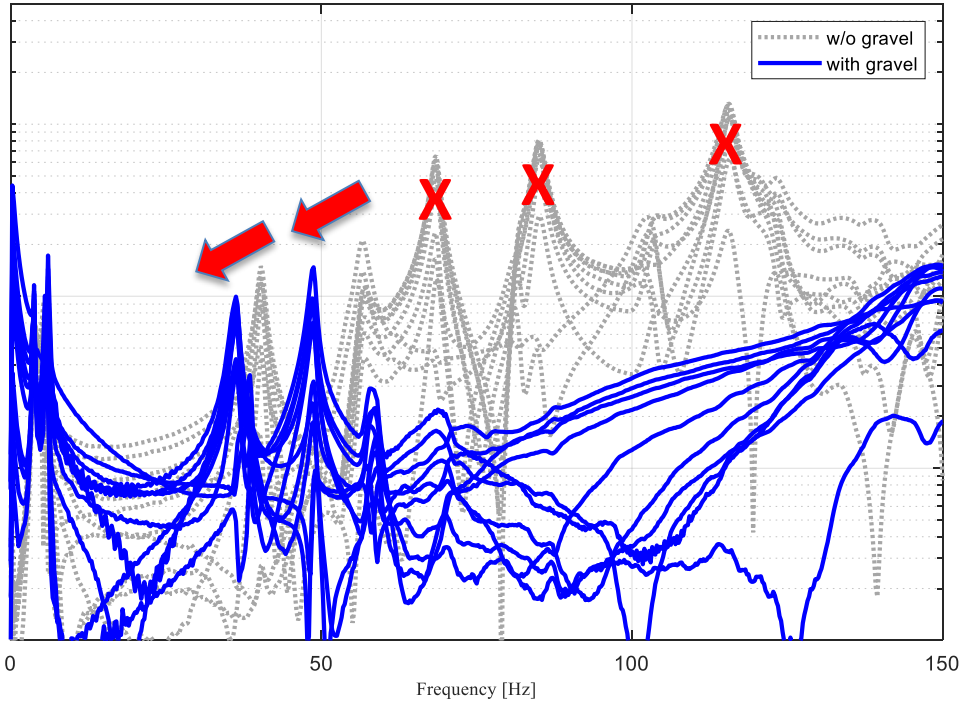
With gravel

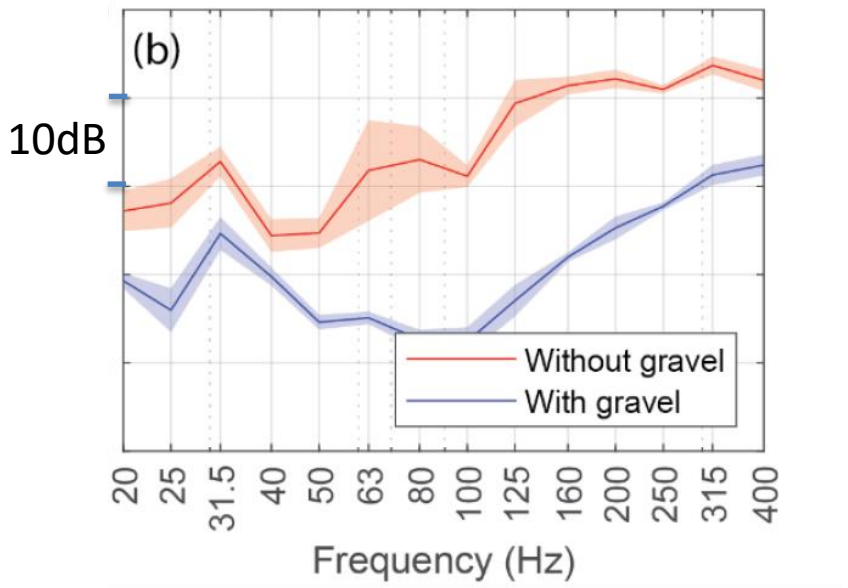
Effect of additional mass

Free - free

Without gravel

With gravel





Investigate boundary conditions

Free - free

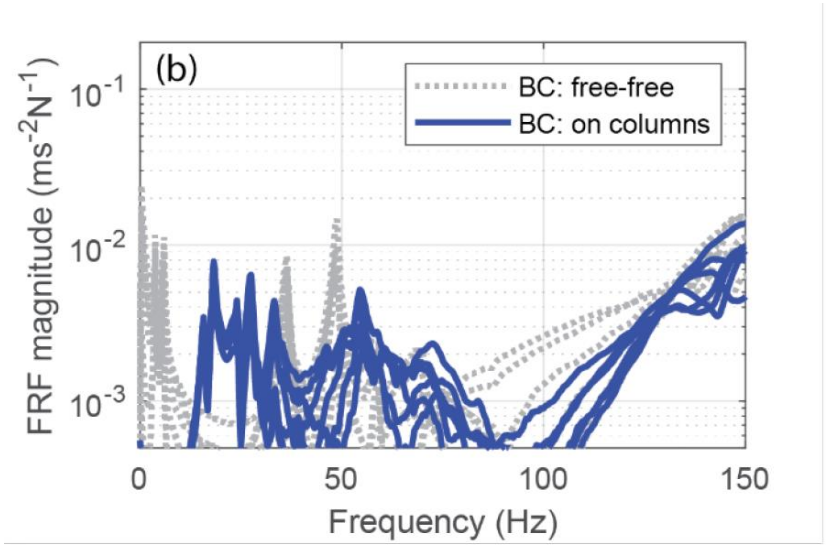
On columns (clamped at the corners)

Effect of boundary conditions

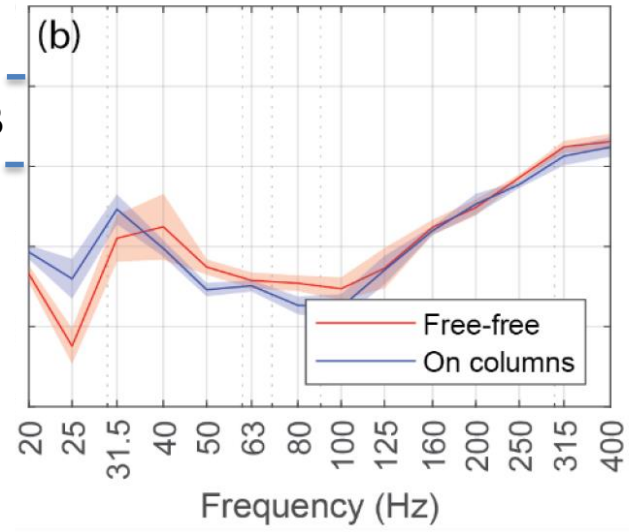
With gravel

Free - free

On columns



10dB



Vibro-acoustic assessment strategy (3)

JUNCTION TRANSMISSION MEASUREMENTS

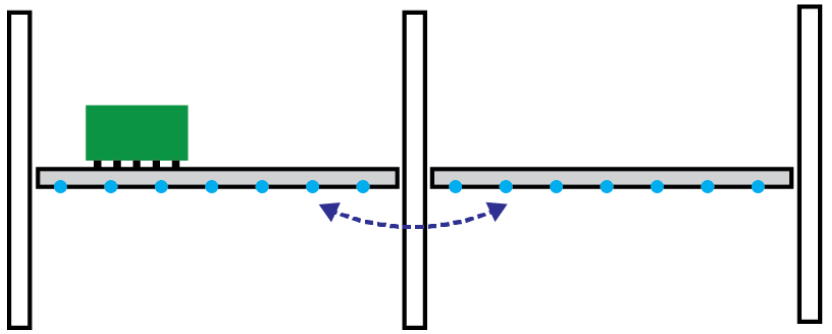
Junction Transmission measurements, JTM

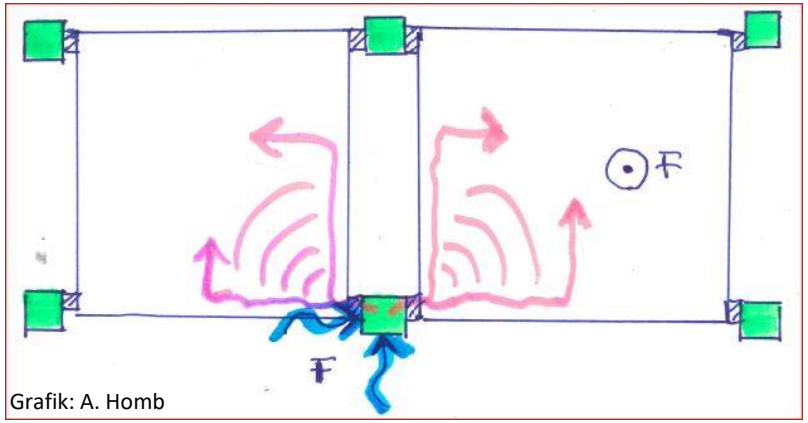
- Assessment of flanking sound transmission
- Based on vibration level difference and structural reverberation time

Kilde: Modal hammer

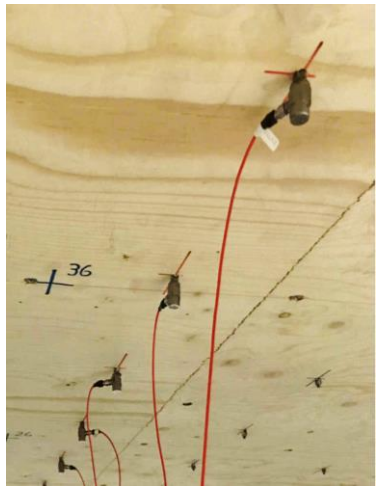
Kilde: shaker

Kilde: bankemaskin



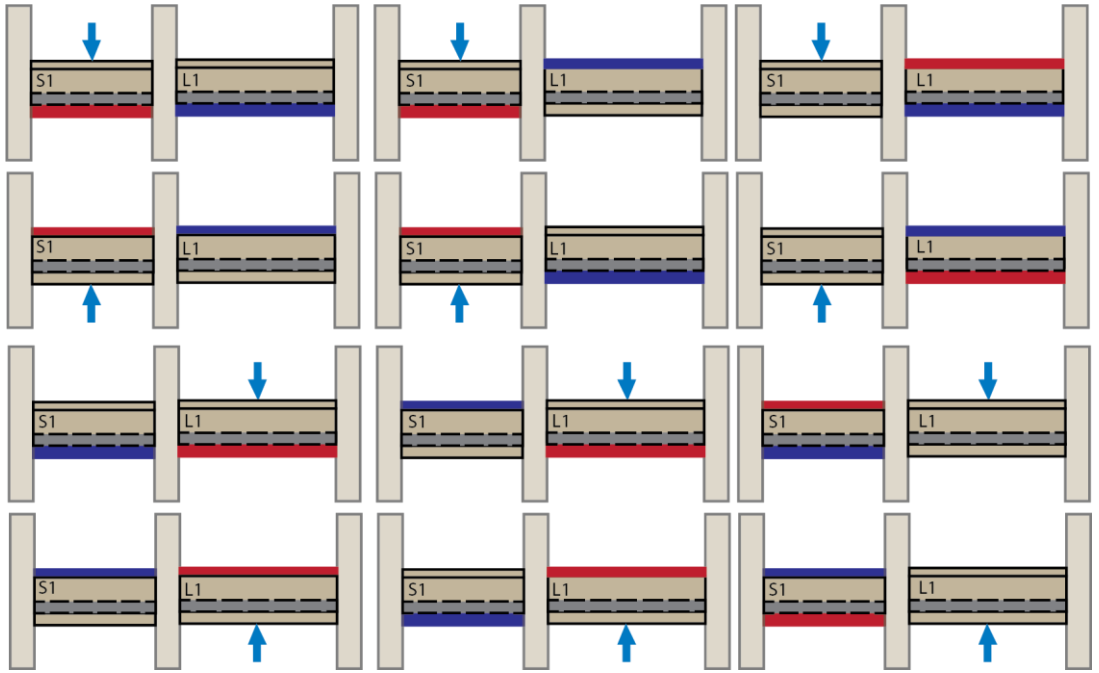


Grafik: A. Homb



Mottaker: akselerometer

JTM / ISO10848-1



- Vibration level difference characterize joint and connectors, K_{ij}
- Input data to calculations according to ISO 12354-1

Summary

- WOODSOL is a Norwegian project aiming at developing timber solution for
  - Urban buildings (apartments, offices, …)
  - Long span (> 9m)
  - Moment resisting frames (reduced bracing)
  - Practical solution are being developed and documentation will be public available (www.woodsol.no)
- We adopted a vibroacoustic strategy that reduces the need for laboratories and allows for advanced assessments «on site»
- Brief insight in the experimental methods (ITM)
- Showed sample results illustrating how we can use advanced measurement methods in building acoustics

HØSTMØTE2019

Takk for meg!

Simone.Conta@ntnu.no
www.woodsol.no

NTNU
Kunnskap for en bedre verden

WOODSOL

WOODSOL in practice

LØVSETH + PARTNER AS
WOODSOL

WOODSOL in practice

LØVSETH + PARTNER AS
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PLAN 1. ETG.