Willkommen
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Bienvenue

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Materials Science and Technology

Current (and future) trends in acoustic materials

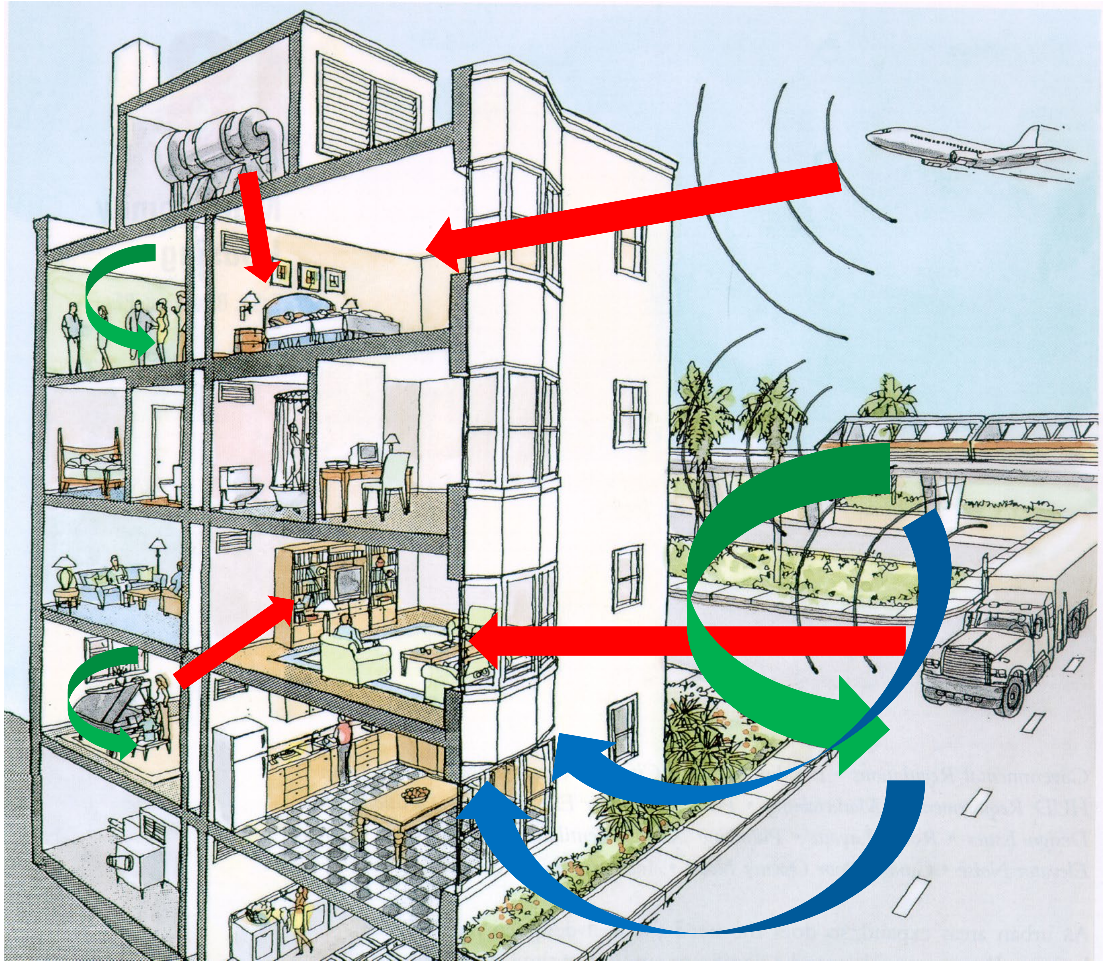
SGA Herbsttagung 3 December 2021

Dr. Bart Van Damme

Use of acoustic materials

- Reduce transmission
  - out->in
  - in->in
- Improve absorption
- Mitigate vibrations

- Some trends
  - Lighter
  - Less material volume
  - 'Smart'
  - Ecological
  - 'Contradictory' materials

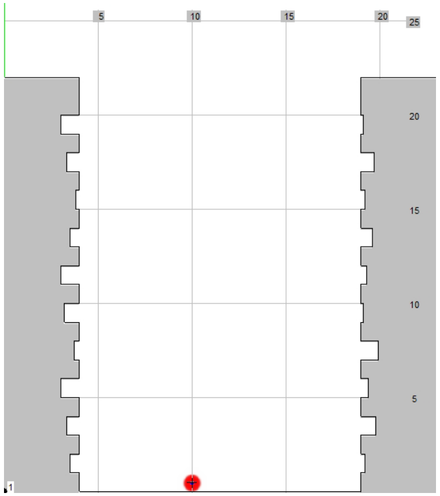


Advances in acoustic materials

- Easier access to
  - Calculation power (from cellphone to desktop to cluster)
  - Visualization methods (SEM, X-ray, …)
  - Production (rapid prototyping)
  - Other fields of science (quantum mechanics, biology, …)
- From trial-and-error to model-based acoustics

Scale model

FDTD



Virtual reality

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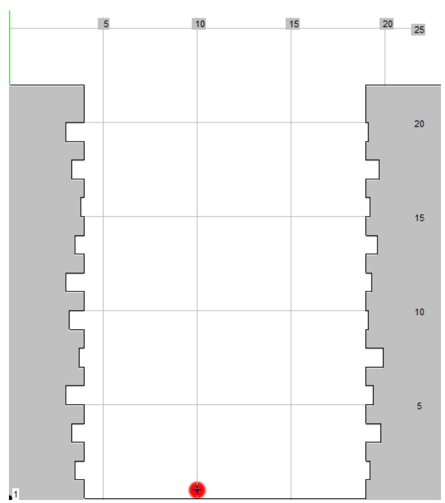

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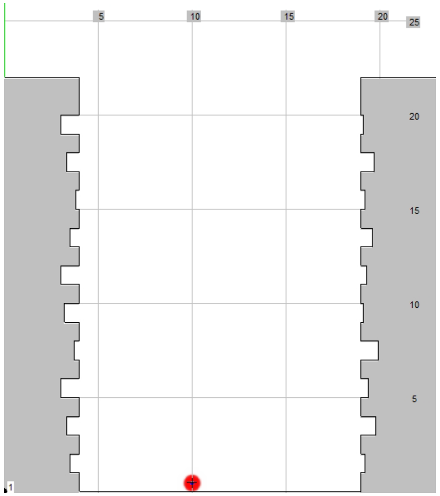

Virtual reality

Advances in acoustic materials

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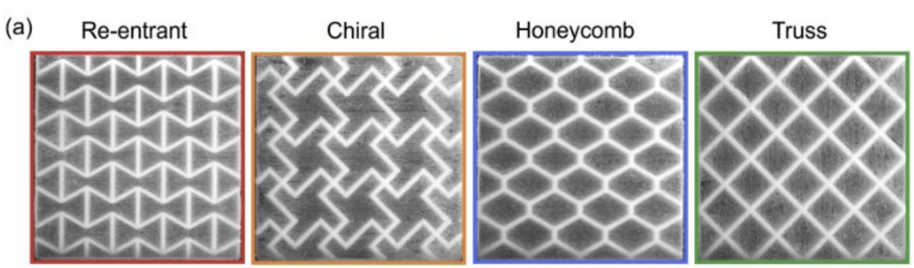
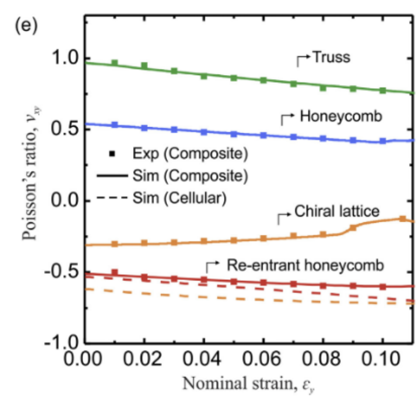
- We cannot change nature (or material properties) but we can change structures

- Combine natural effects to achieve the desired property: metamaterials have three scales
  - Micro: the base material(s)
  - Meso: an engineered cell
  - Macro: an assembly of cells with a macroscopic property different from the base material



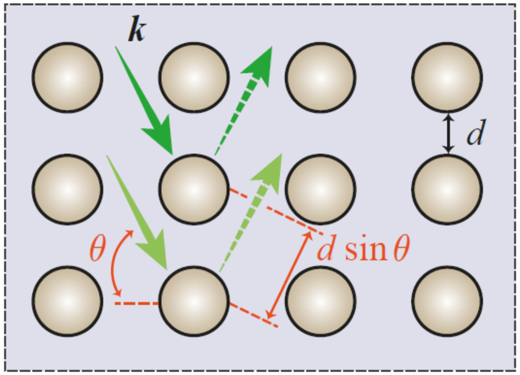


Li, Tiantian et al. *Materials & Design* 142 (2018): 247-258.

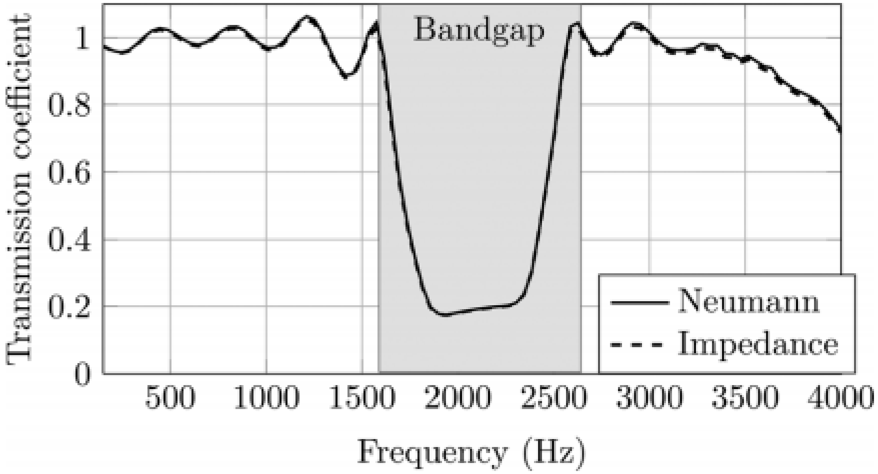
Materials for sound transmission

- Classical solution
  - Heavy materials (mass law)
  - Double-leaf walls
- In periodic structures, waves are scattered in a special way
  - Constructive and destructive interference
  - Depends on size and angle

Bragg scattering:



$$2d \sin\theta = n\lambda$$



Lagarrigue, C. et al. *The Journal of the Acoustical Society of America* 133, no. 1 (2013): 247-254.

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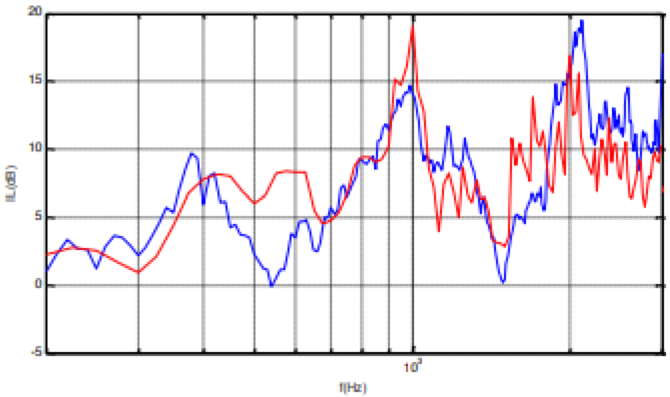
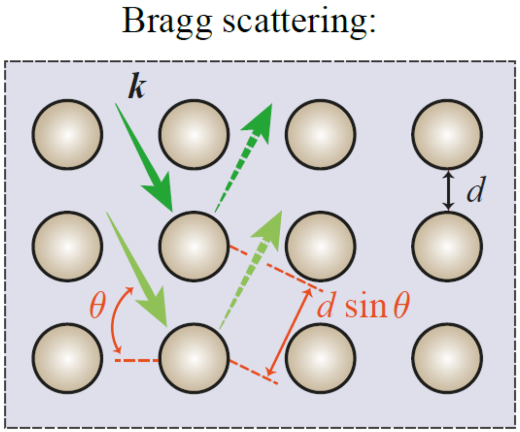


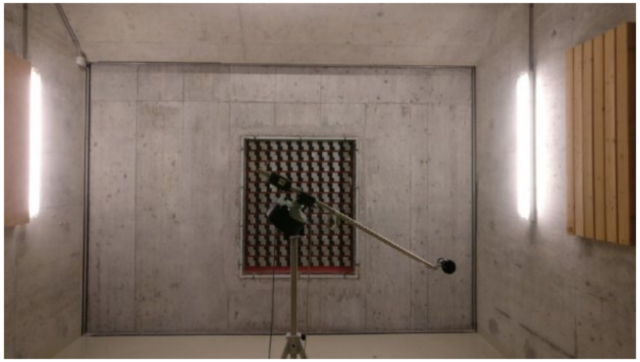
Amado-Mendes, P., et al. *Proceedings of the International Congress on Acoustics*. 2016.

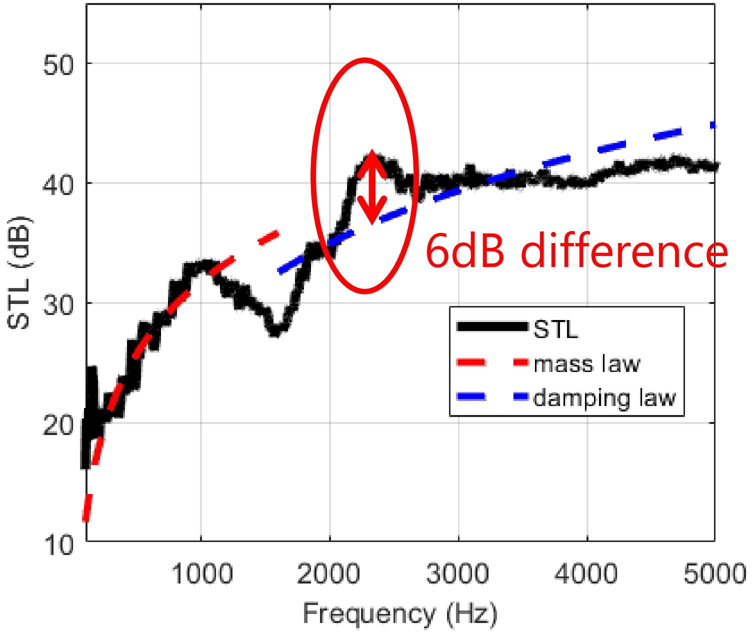


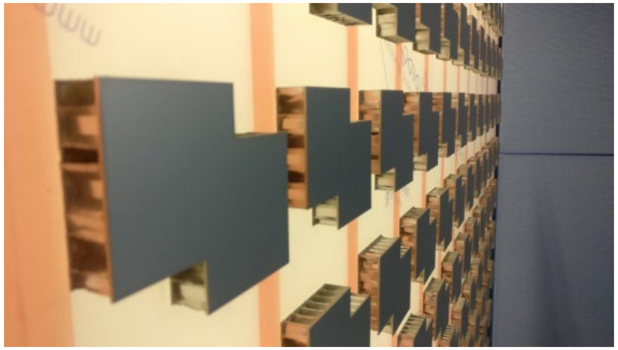
$$2d\sin\theta = n\lambda$$

Materials for sound transmission

- Periodic media lead to lighter solutions
  - Less material
  - Transparent
  - Open/ventilation possible
- Modelling often needed
- Collaboration with industry partners to increase visibility and show potential



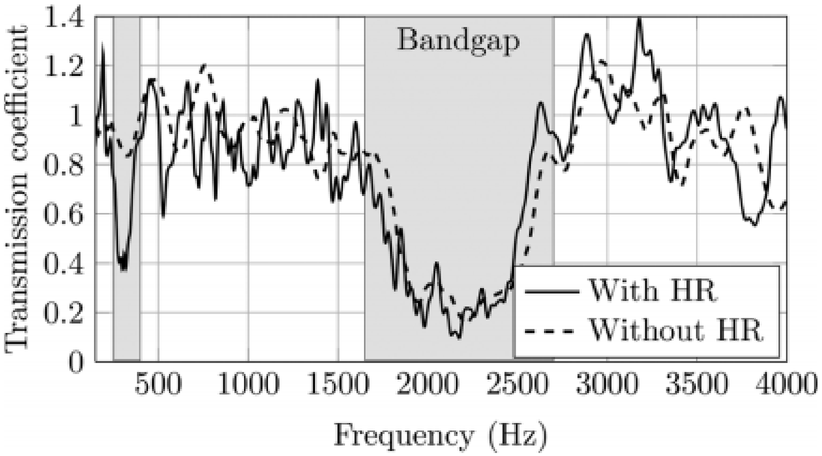




Van Damme, B., et al. *ISMA, Leuven* 2018.

Adding resonance: sound transmission

- Periodic media need scale in the range of a wavelength
  - At 1000 Hz: 34 cm
  - At 100 Hz: 3.4 m
- Lighter than traditional solution, but not smaller
- Adding resonators can add low-frequency effects independent of the size



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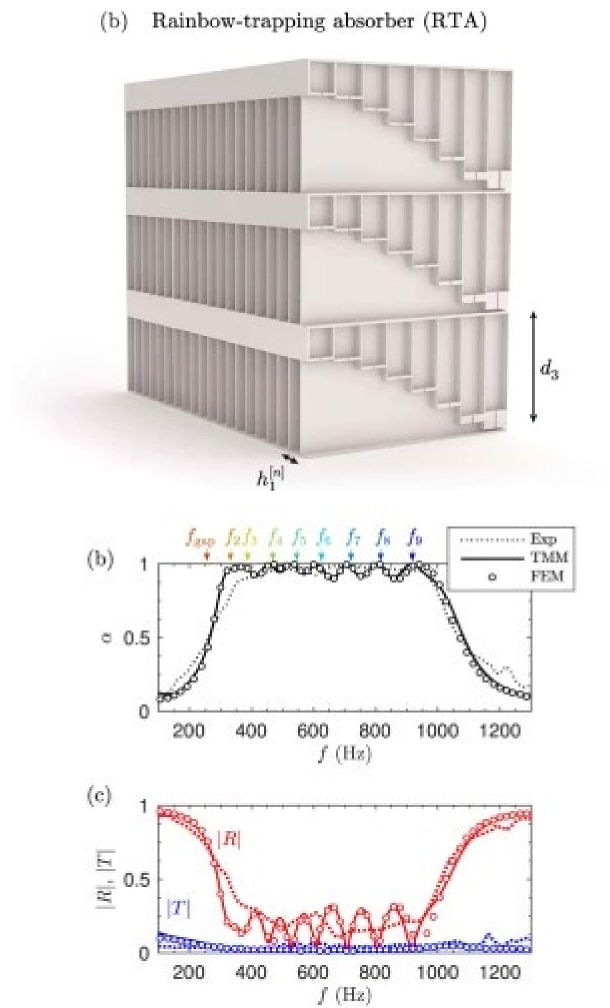

Jiménez, Noé, et al. *Scientific reports* 7.1 (2017): 1-12.

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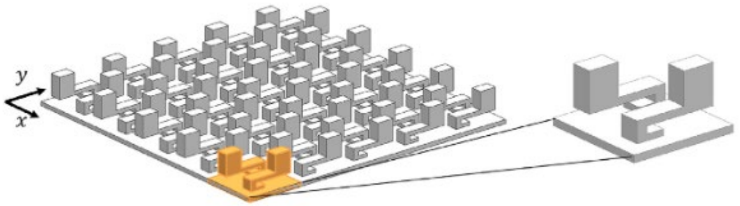

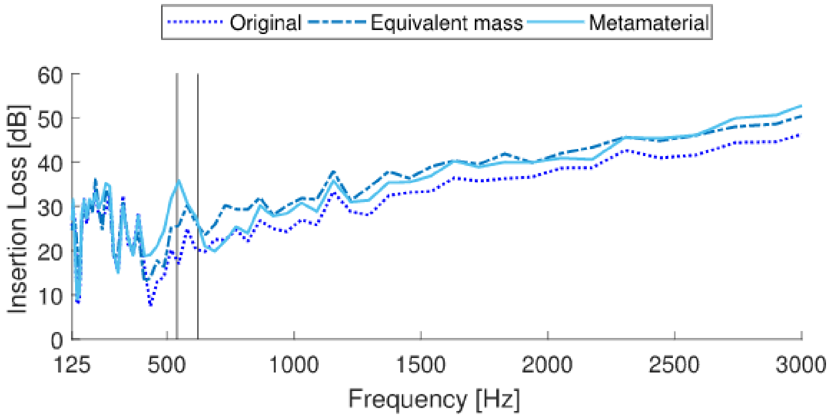

de Melo Filho, N. G. R., et al. *Journal of Sound and Vibration* 442 (2019): 28-44.

Materials for sound absorption

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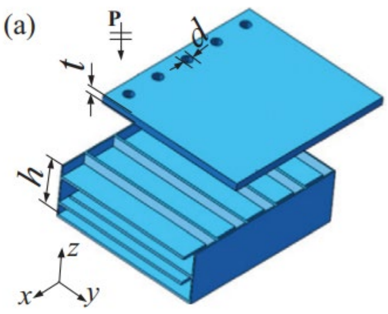
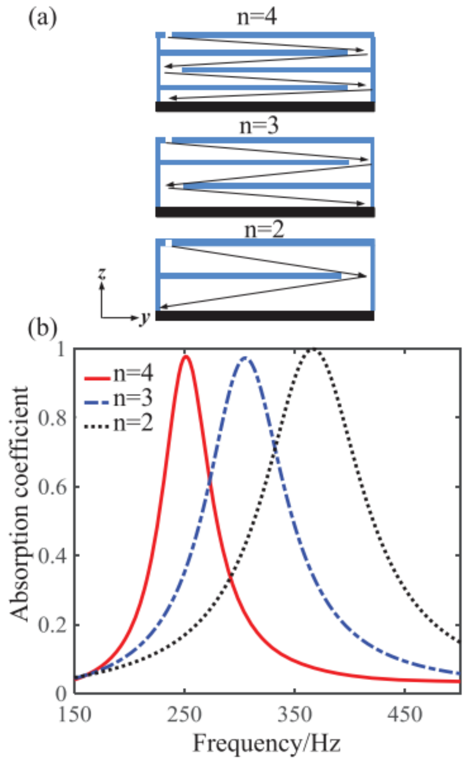
- Classical material: porous media
  - Viscous and thermal energy losses
  - High absorption for thickness $\mathrm{h} > \lambda/4$
- Increase thickness by geometrical tricks
  - Labyrinth structure
  - Optimized geometry
- Typical high absorption in narrow frequency range, but much lower than for traditional materials
  - Deep-subwavelength absorbers, $\mathrm{h} < \lambda/10$

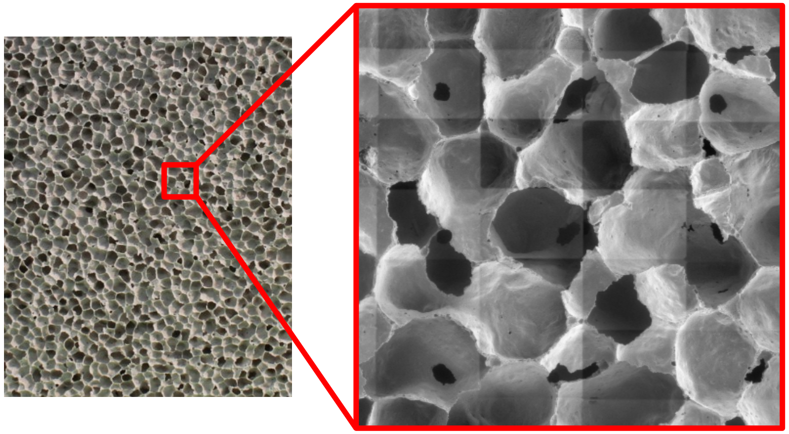


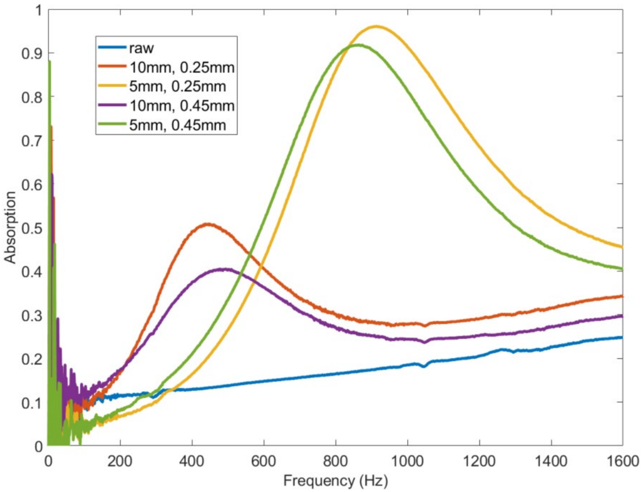


Wang, Yang, et al. *EPL (Europhysics Letters)* 120.5 (2018): 54001.

Materials for sound absorption

- Standard porous media do not have ideal properties for absorption at all frequencies
  - Flow resistance (higher or lower absorption)
  - Tortuosity (higher or lower frequency)
- Combine techniques to improve absorption:
  - Foam properties
  - Perforated screens
  - Perforations
  - Microporosity/multiple scale porosity
- Find ideal configuration based on models, instead of increasing amount of material

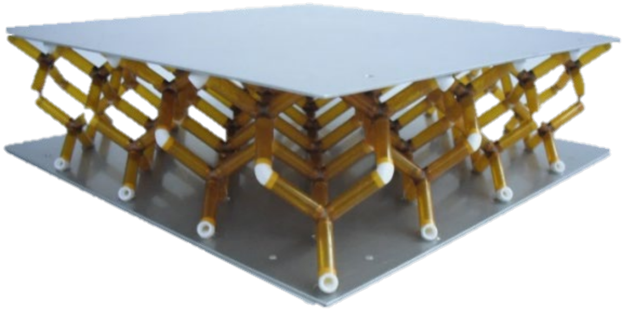


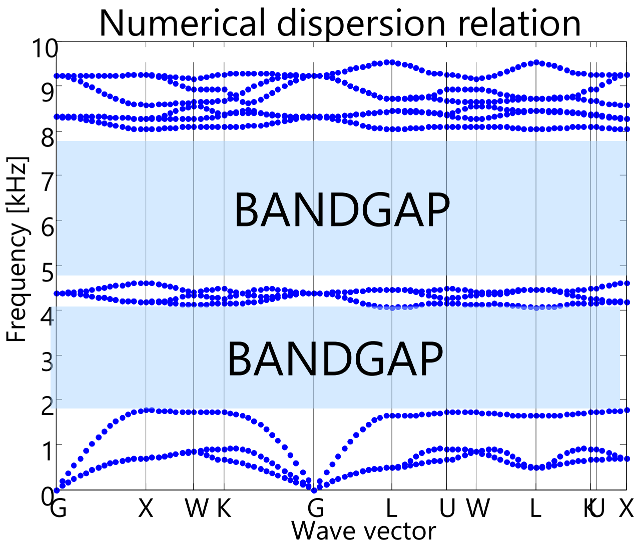


Van Damme, Bart, et al. *Forum Acusticum*. 2020.

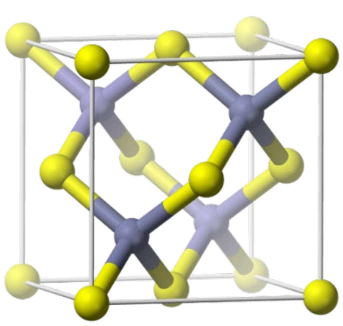
Materials for vibration isolation

- Placed under vibrating sources to decouple them from environment
- Traditional materials
  - Soft (low resonance frequency)
  - High visco-elastic losses
- How to find stiff, light, and attenuating materials?
  - Quantum mechanics: electron waves cannot propagate in certain frequency ranges in crystals





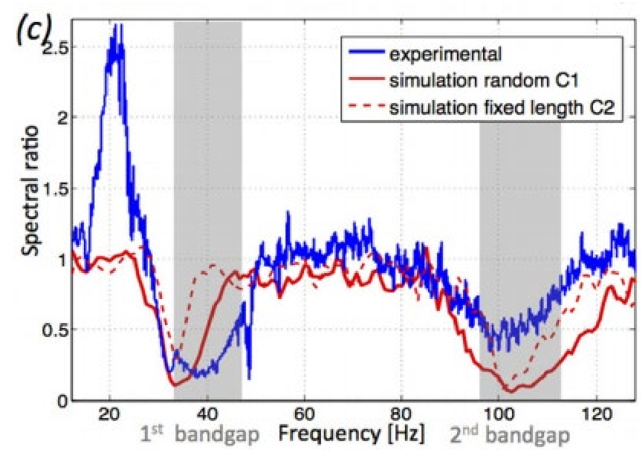
Delpero, Tommaso, et al. *Journal of Sound and Vibration* 363 (2016): 156-165.

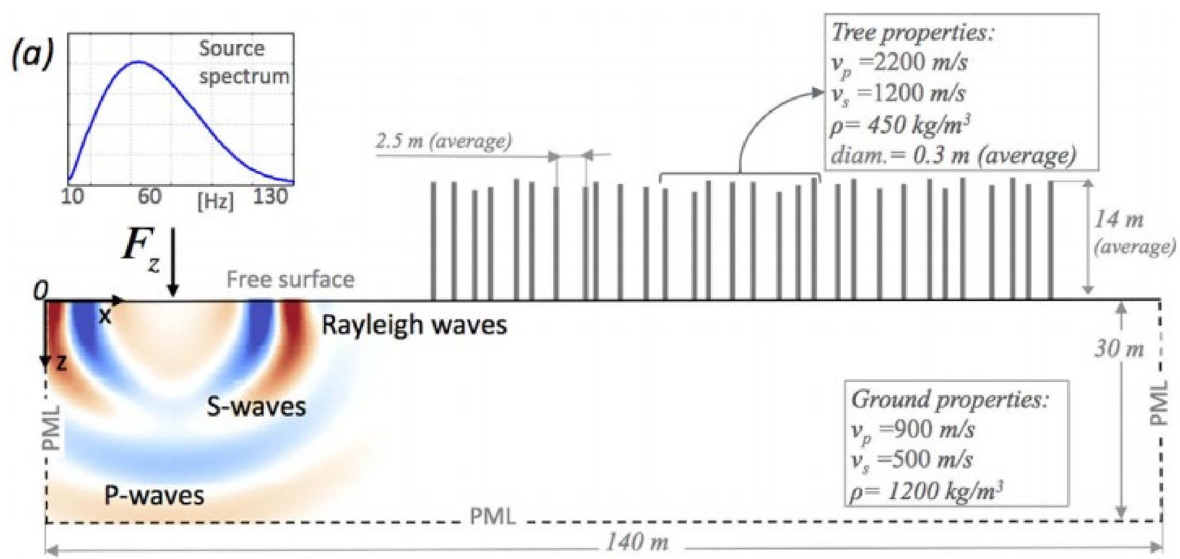


Source: J. Phys.: https://en.wikipedia.org/

Materials for vibration attenuation

- Add resonators to achieve lower frequencies
  - seismic waves contain very low frequencies and very large wavelengths
  - Large resonators: use trees





Colombi, Andrea, et al. *Scientific reports* 6.1 (2016): 1-7.

Materials for vibration attenuation

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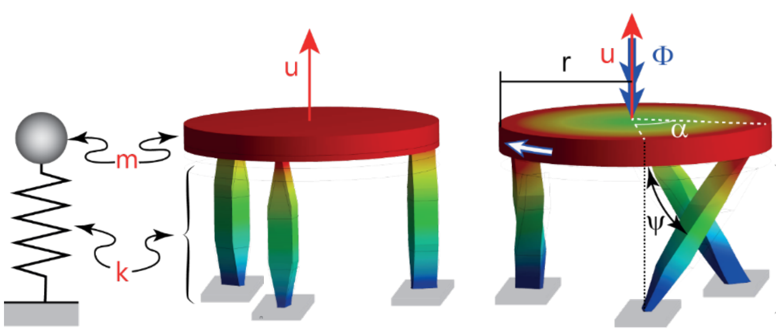
- We can do more with less!
  - Dynamic mass ≠ static mass
  - Coupling translation to rotation leads to higher effective mass and lower resonance frequency
- Inertia amplification is effective to bring isolation frequency down while keeping stiffness up

Isotactic Syndiotactic



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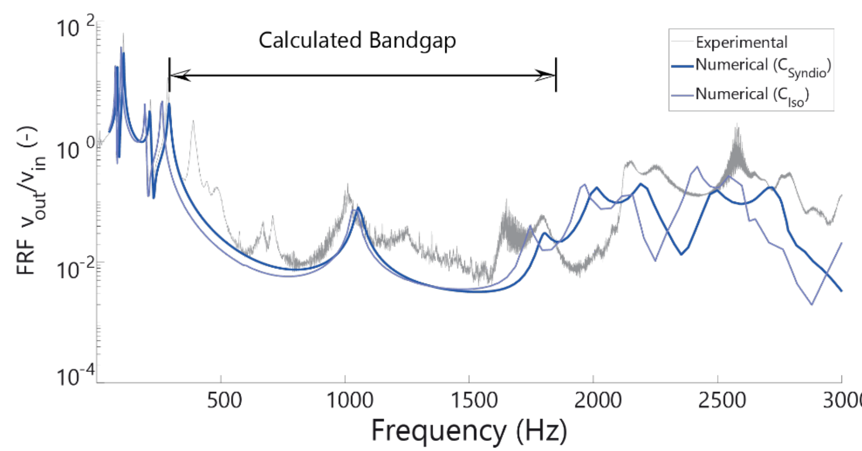
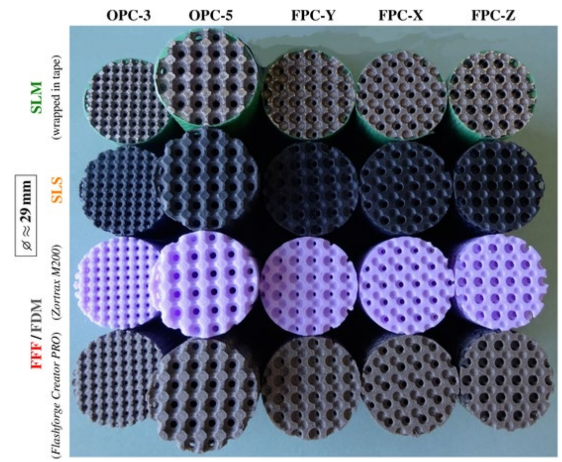


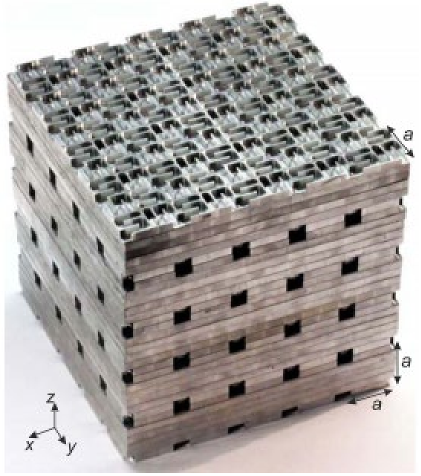
Bergamini, A., et al. *Nature communications* 10.1 (2019): 1-8.

Production: rapid prototyping

- Print absorbing/isolating materials
- More freedom in achieving any geometry
  - Absorption
  - Slow sound
  - Complex resonators
- How reliable is the geometry?
- How economical can this be done?



Zieliński, Tomasz G., et al. *Additive Manufacturing* 36 (2020): 101564.



Frenzel, Tobias, et al. *Applied Physics Letters* 103.6 (2013): 061907.

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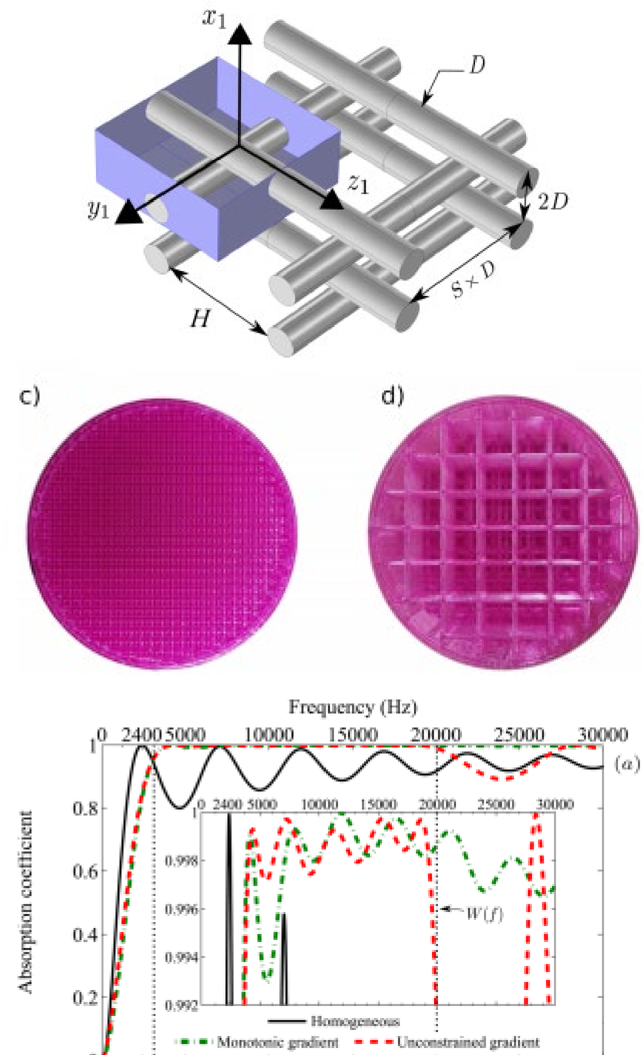

Boulvert, Jean, et al. *Journal of Applied Physics* 126.17 (2019): 175101.

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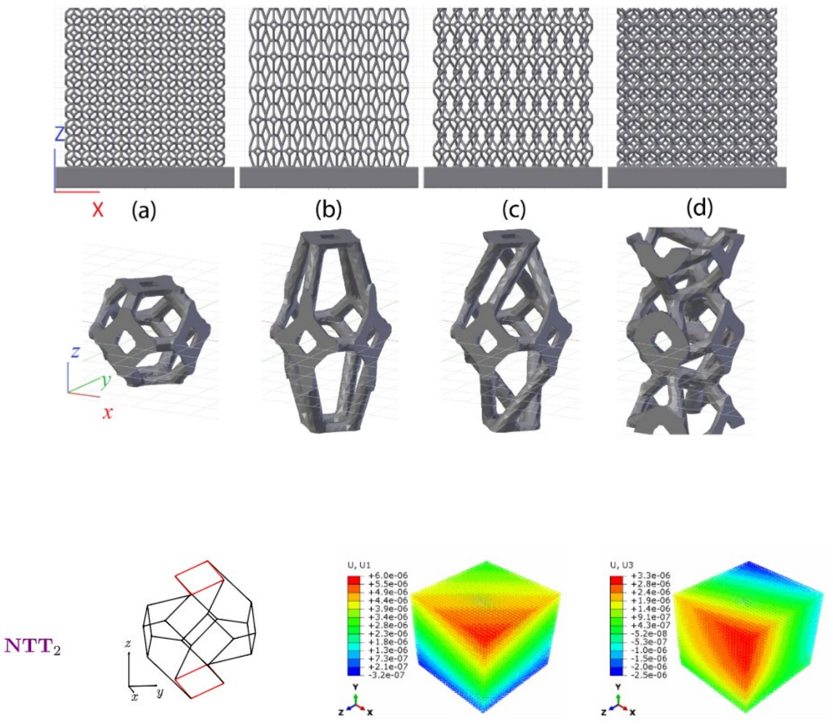

Mao, Huina, et al. *Materials & Design* 193 (2020): 108855.

Future trends

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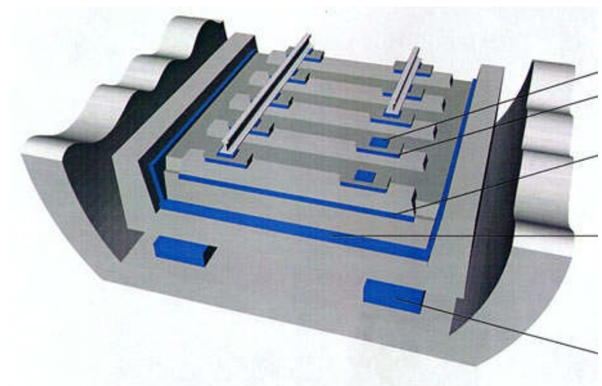
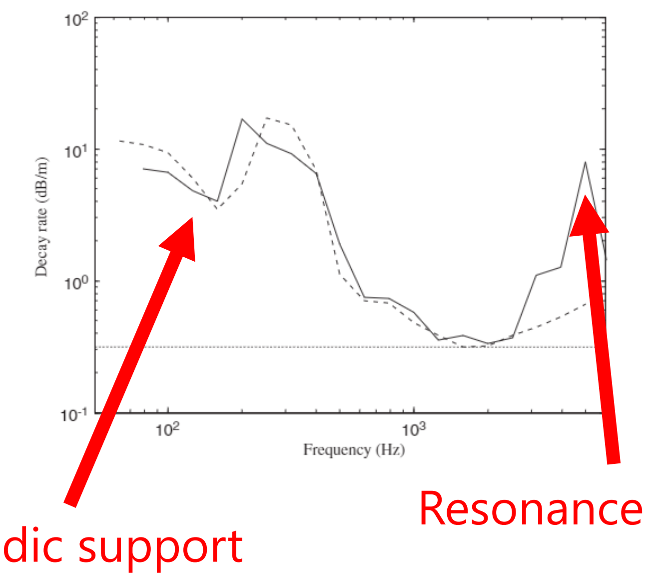
- Many 'exotic' applications: negative refraction, wave guiding, wave localisation
- The industrial interest goes towards 'standard' effects: absorption, transmission, isolation, vibration attenuation
- Better and faster modelling can help new technologies
  - Visualization and auralization to sell the effect
  - Faster numerical models help us investigate more scenarios (and their uncertainties)
    - order reduction
    - parallel computing
    - artificial intelligence / data science
- Many metamaterial concepts have been known for a long time, the past informs us about the future





Thank you

Questions?

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