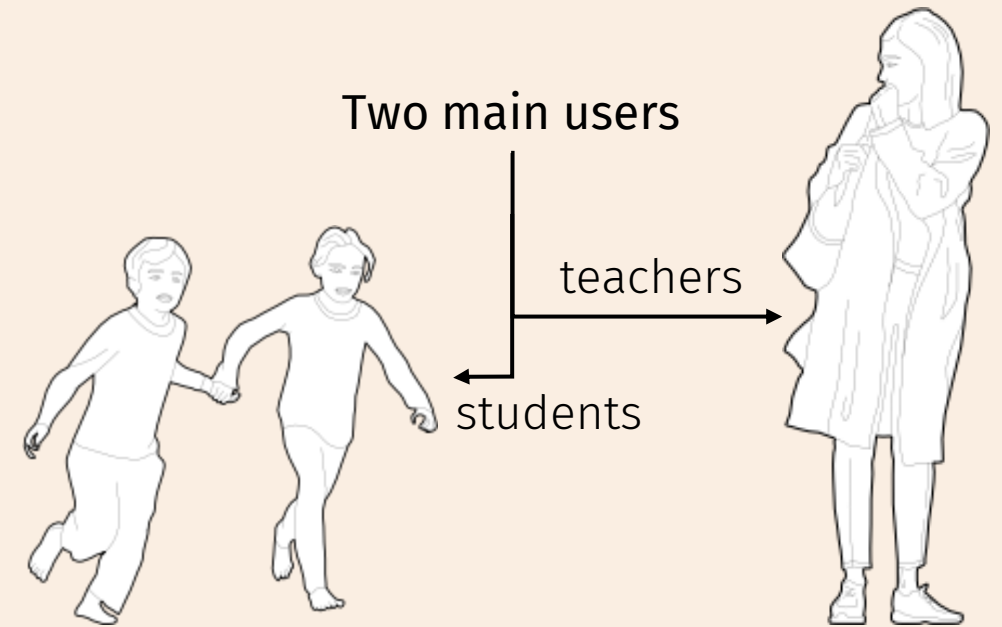




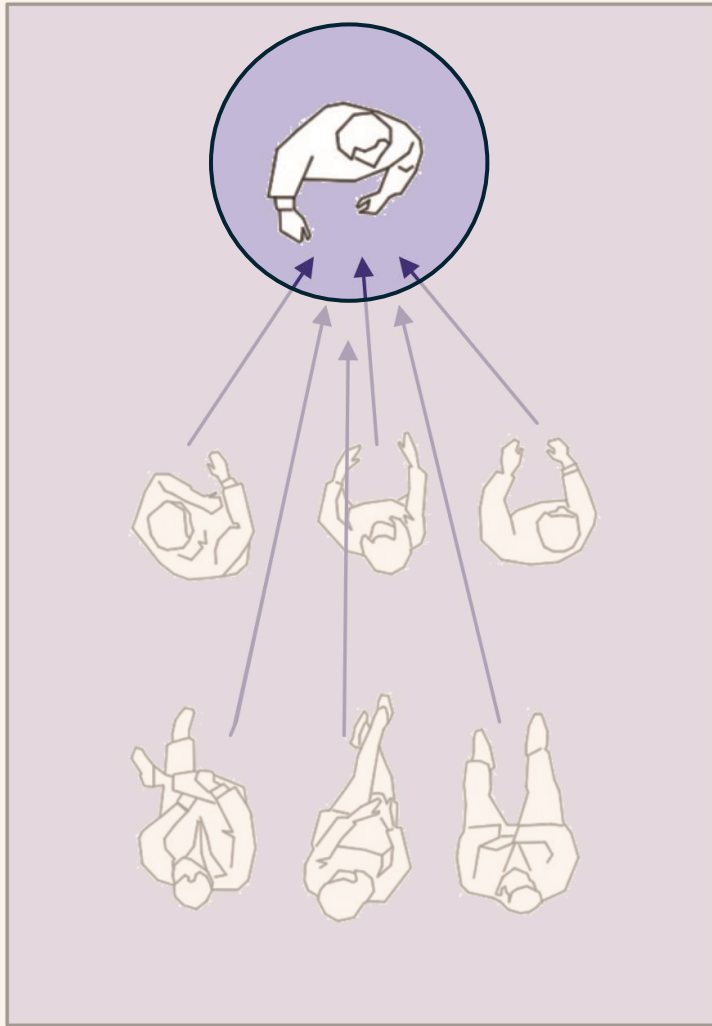
Personalised Control of Indoor Acoustics

In middle schools

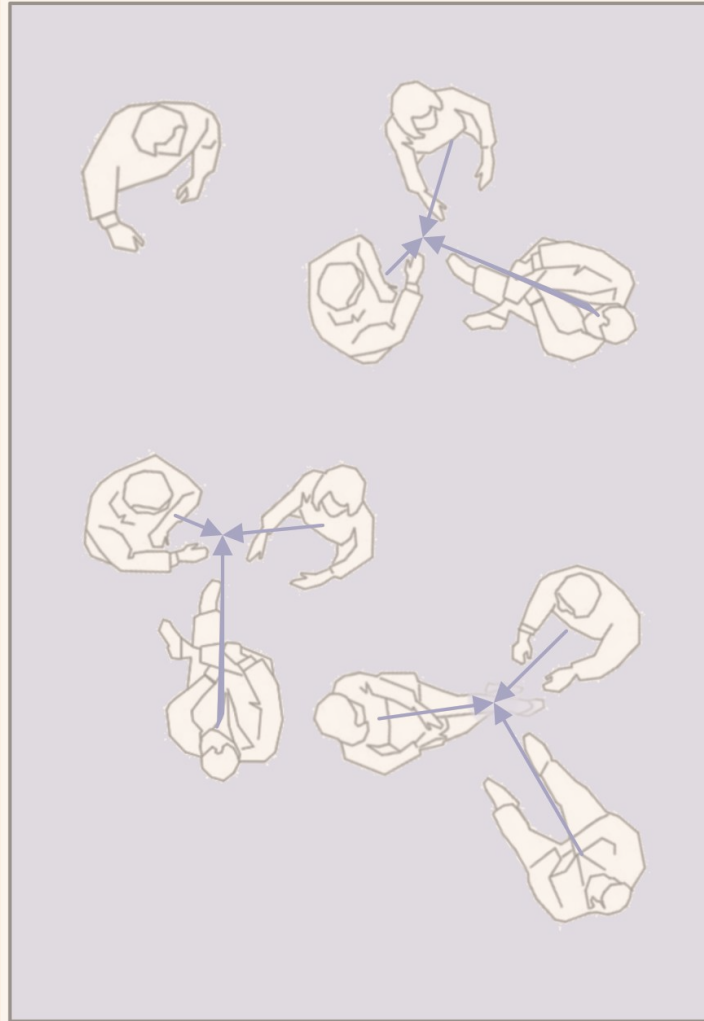
The Classroom



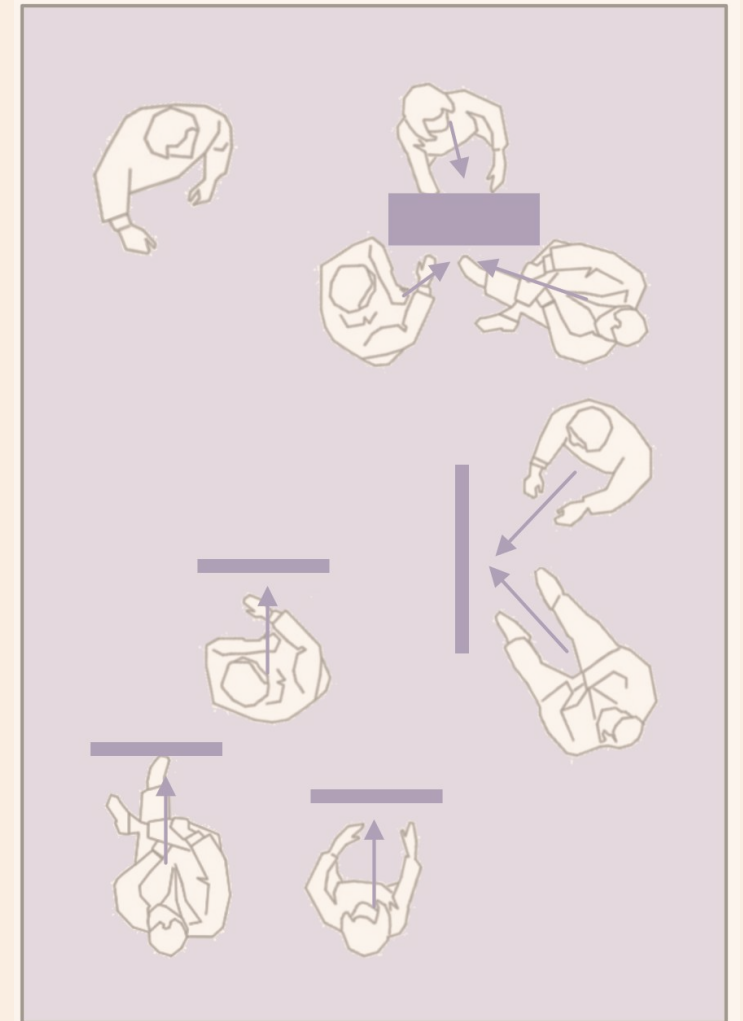
- Vocal effort – talking above the class
 - Impacts health
- Have to listen to the class in presence of noise
 - Impacts learning, social relationships
- Different requirements
- Position in class matters



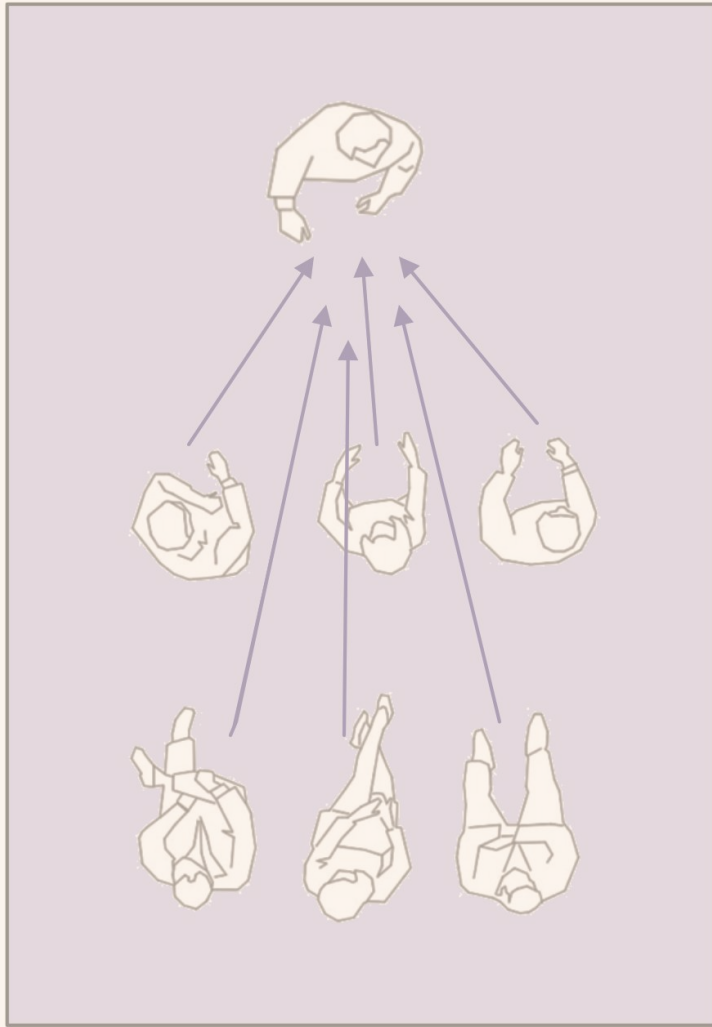
Teacher Focused



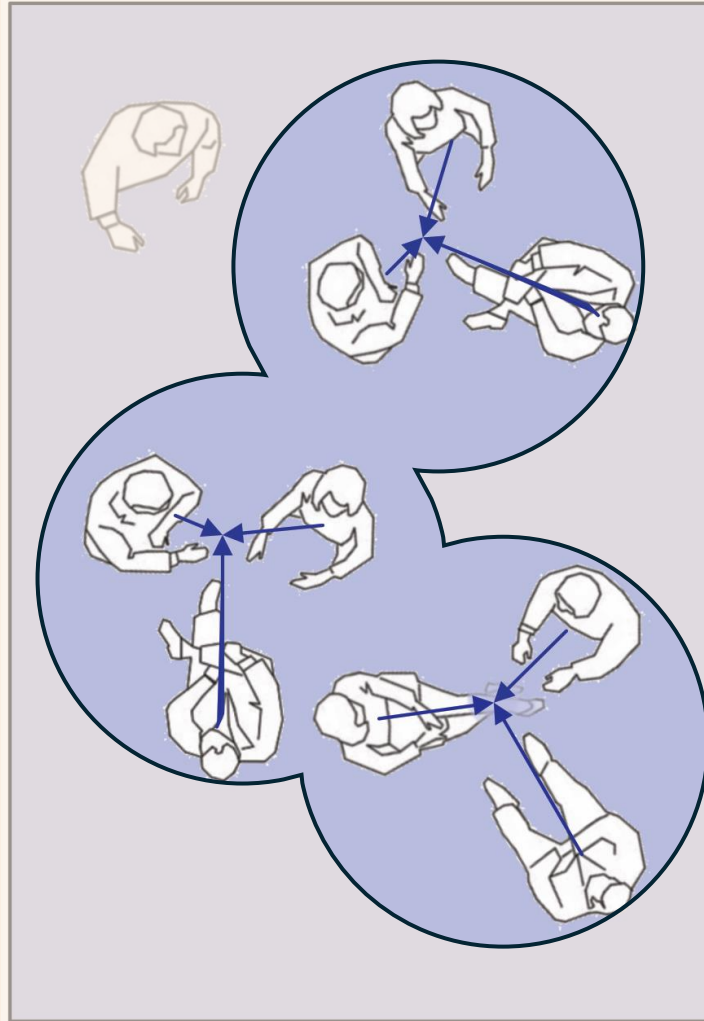
Group Work



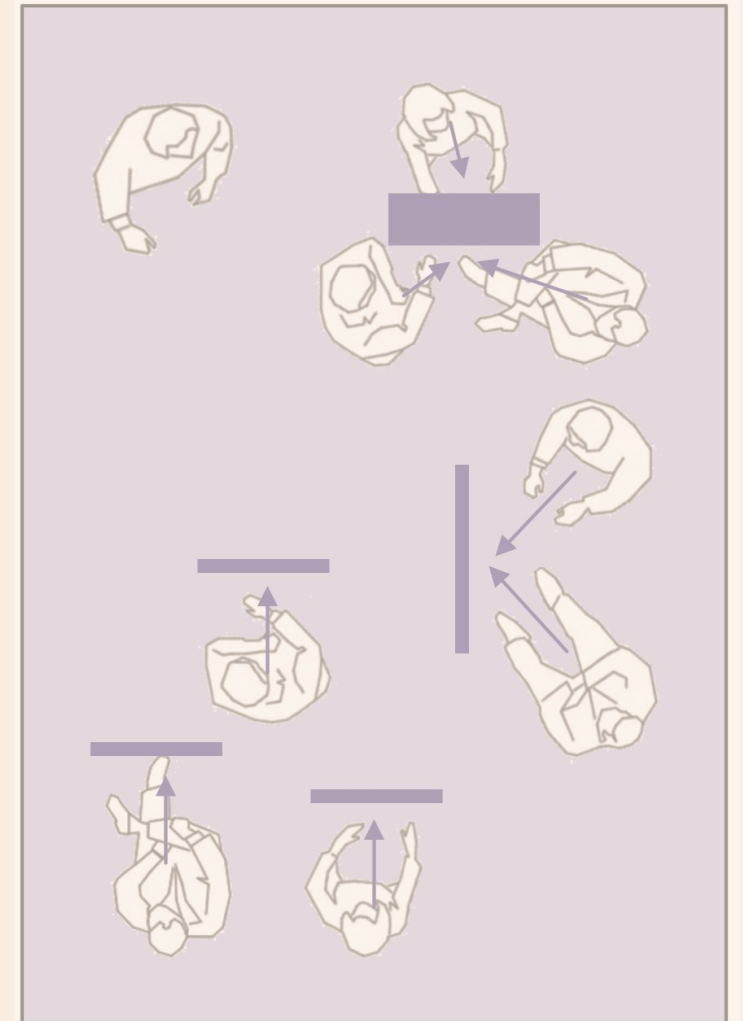
Independent Work



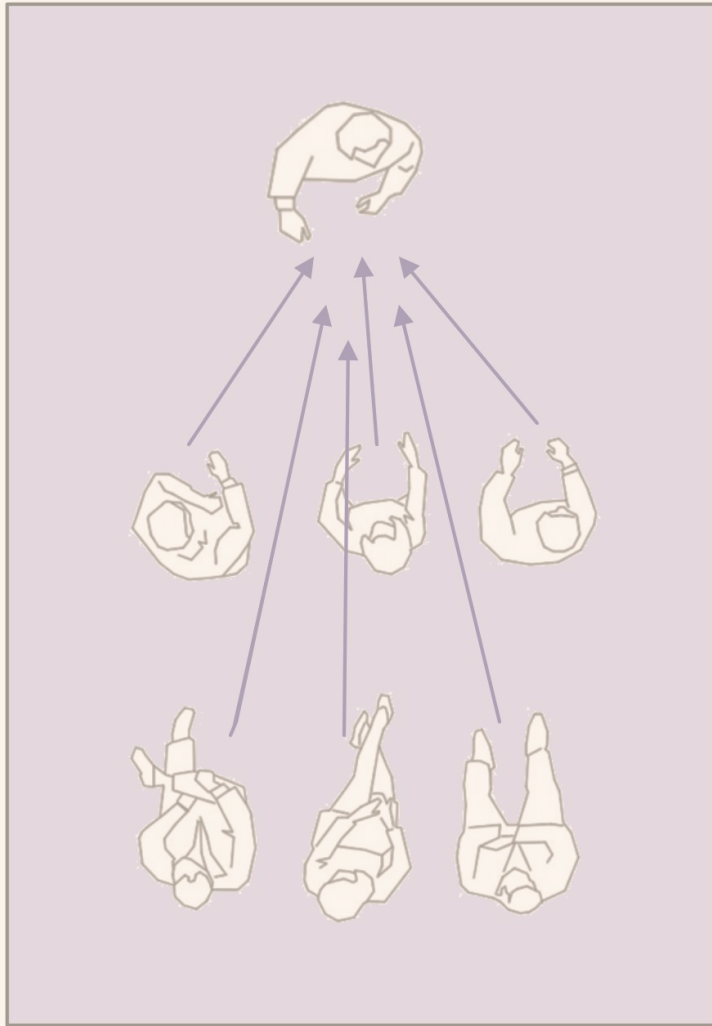
Teacher Focused



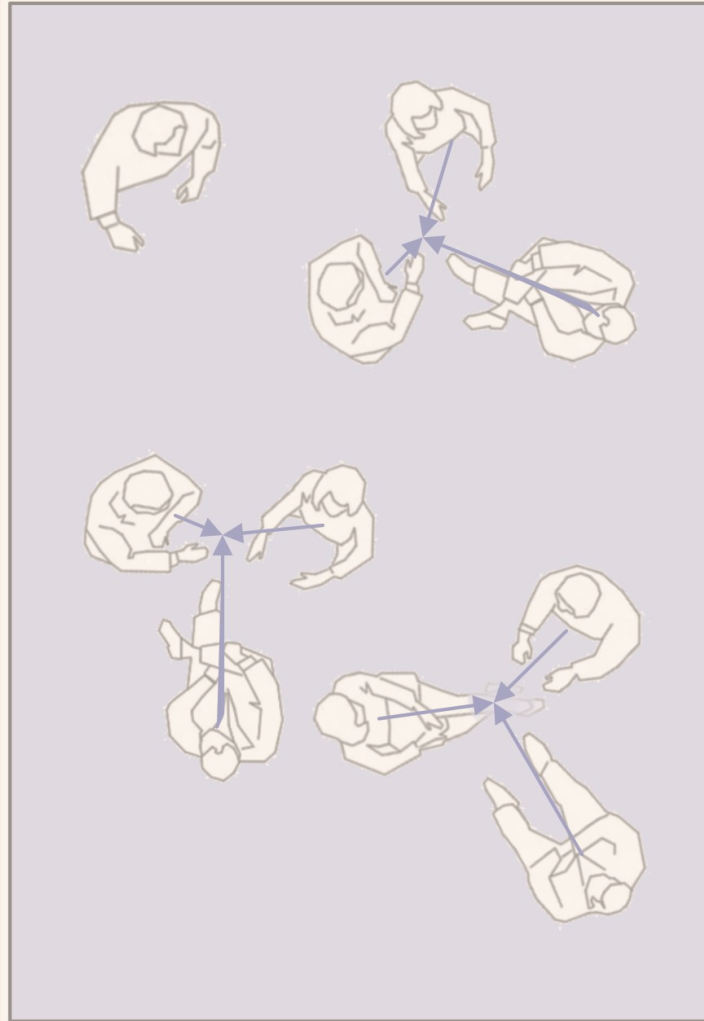
Group Work



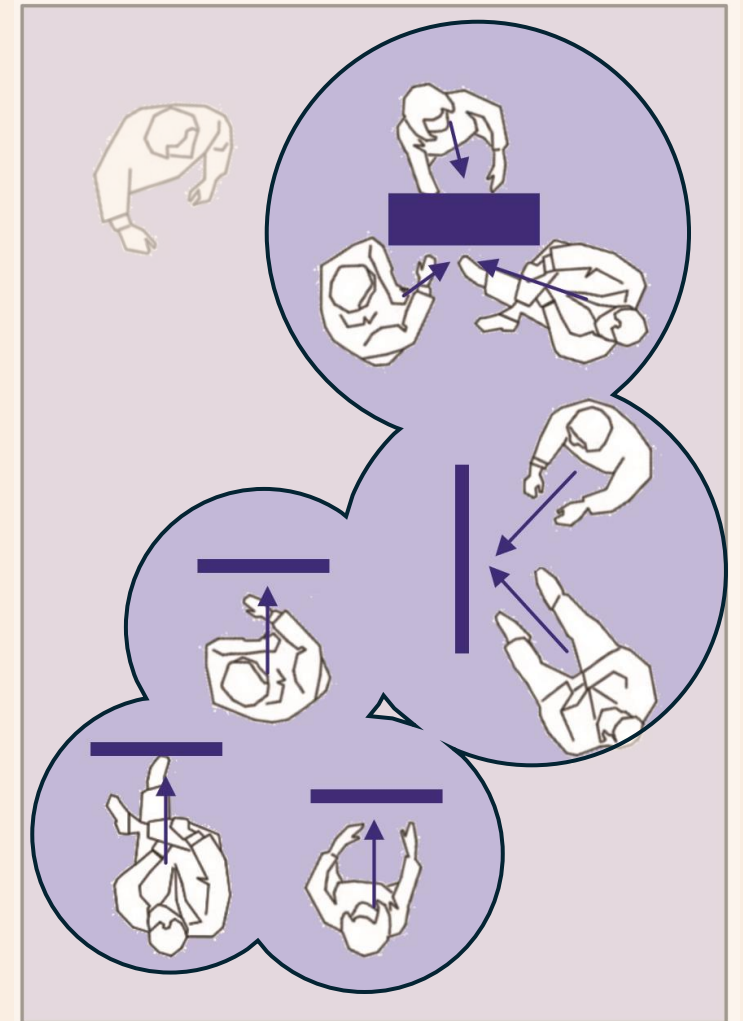
Independent Work



Teacher Focused



Group Work



Independent Work

Passive interventions

Room geometry

Walls

Ceilings

Floors

“Make or break point
of room acoustics”

Acoustic panels

Static

Dynamic

Product
development

Reverberation Time

RT

T_{30}

8

- Persistence of sound after it is produced
- Amount of time for the sound pressure level to reduce by 60 dB after the sound source has stopped

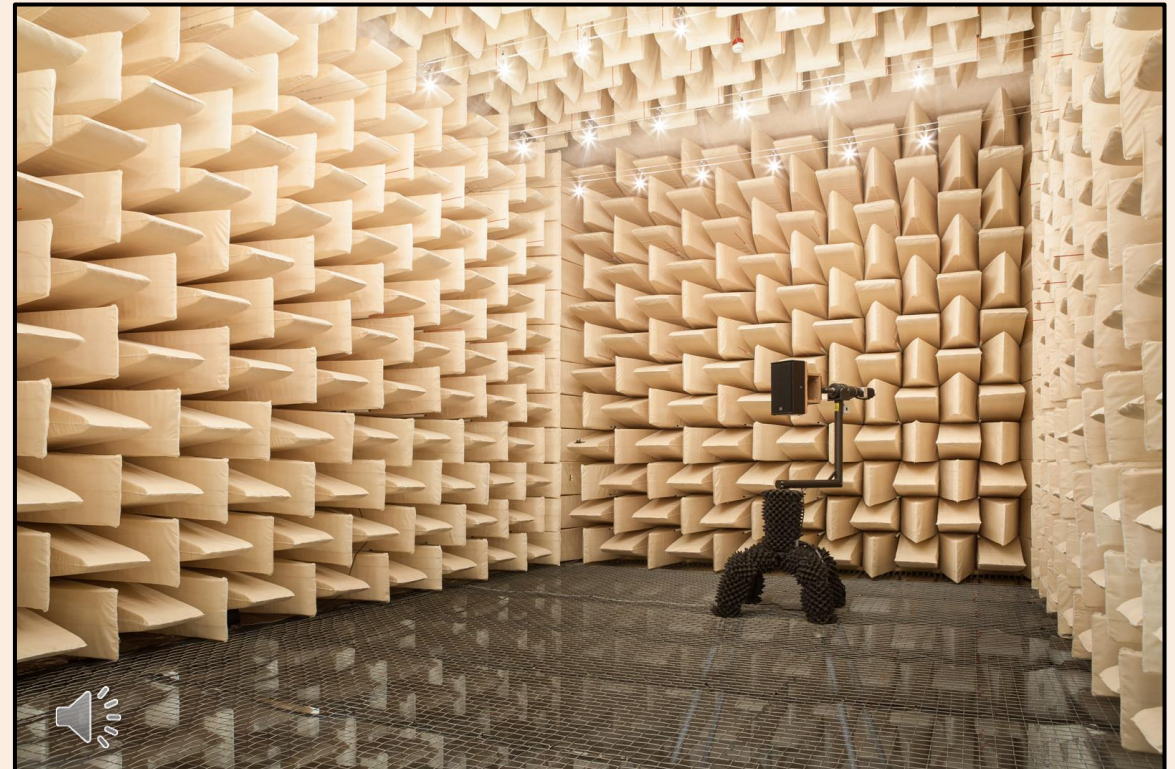


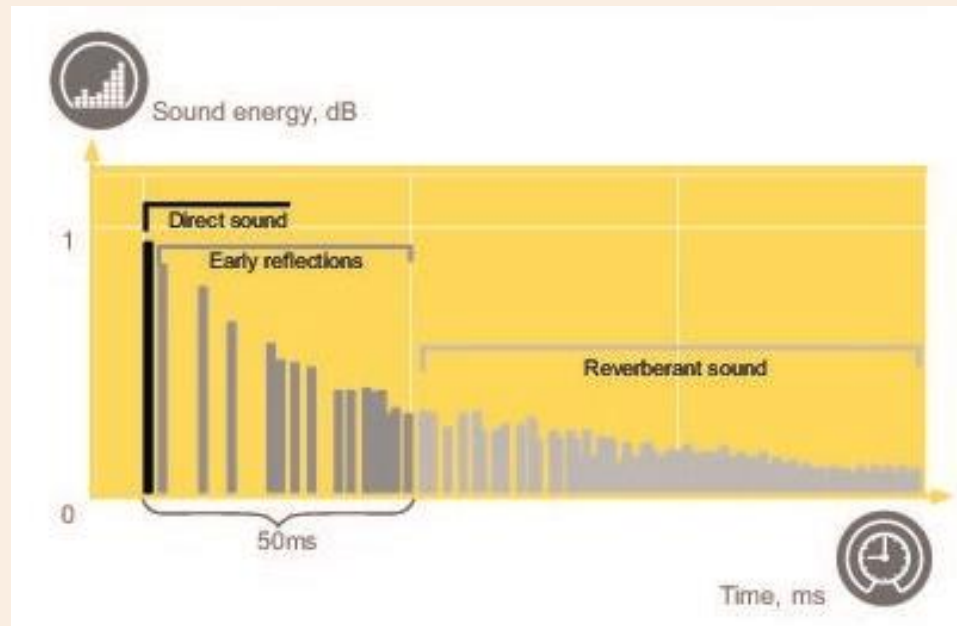
Image sources: <https://soundhub.dk/reverberation-chamber/>, https://www.idmt.fraunhofer.de/en/business_units/acoustics/equipment.html

Speech Clarity

 C_{50} C_{35}

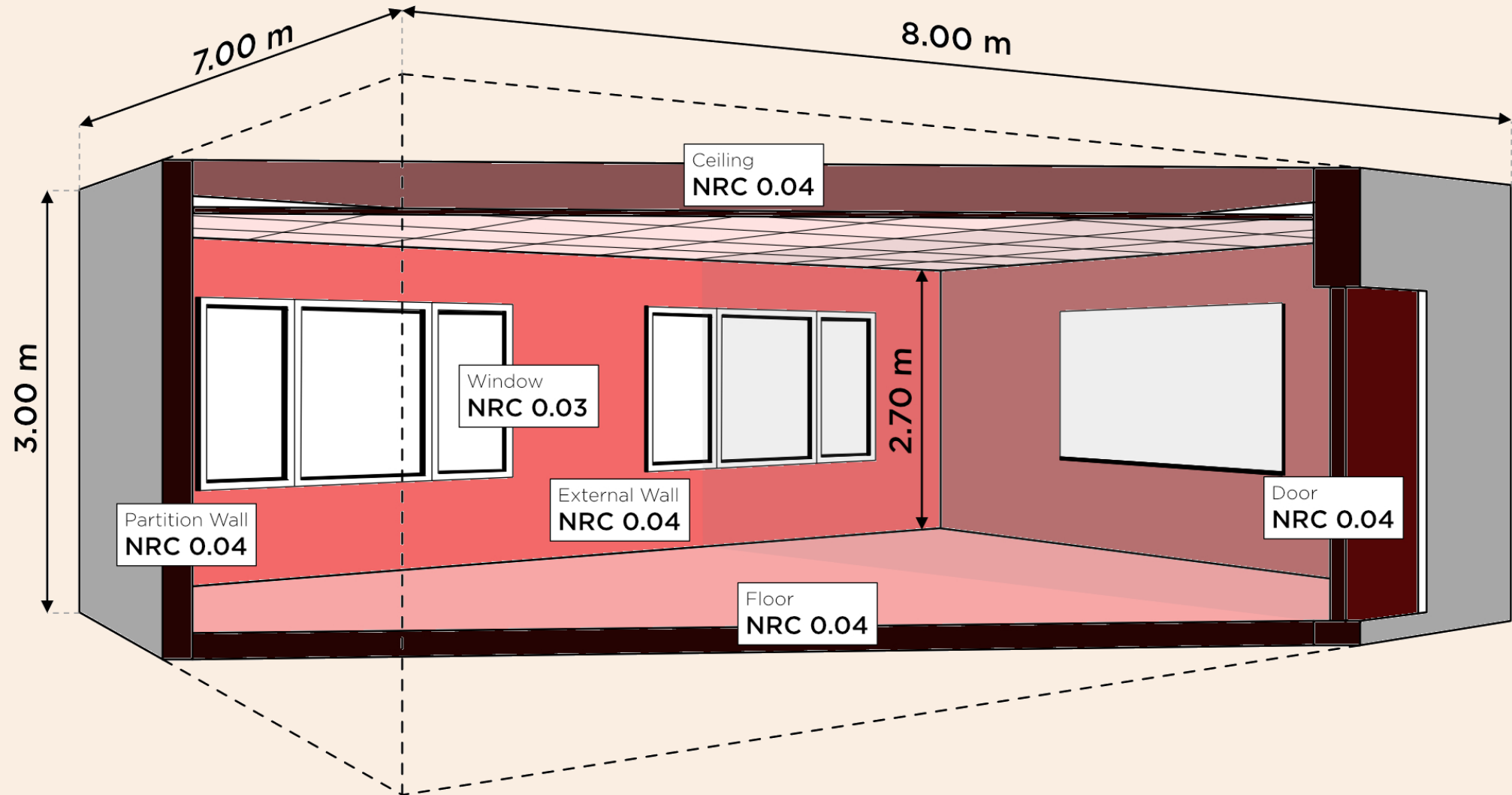
9

- Ratio of sound power present in the first 50ms of impulse response to sound power present after 50ms.
- Under 50 ms – adds to speech clarity
Over 50 ms – takes away from speech clarity
- Children are more sensitive – threshold should be 35 ms



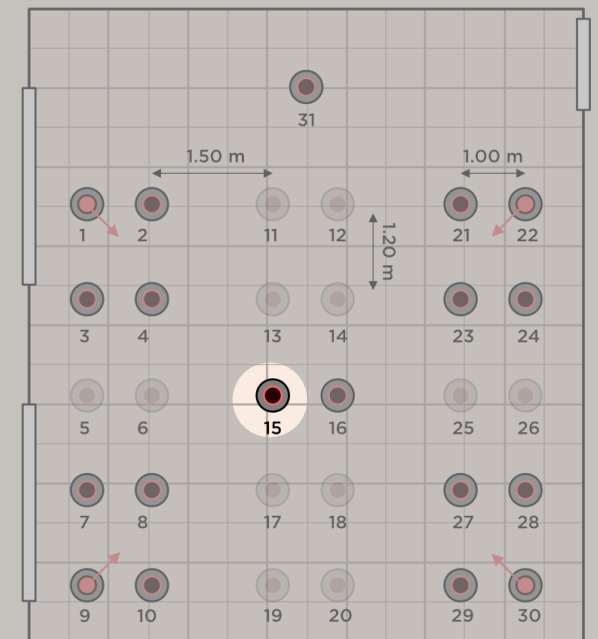
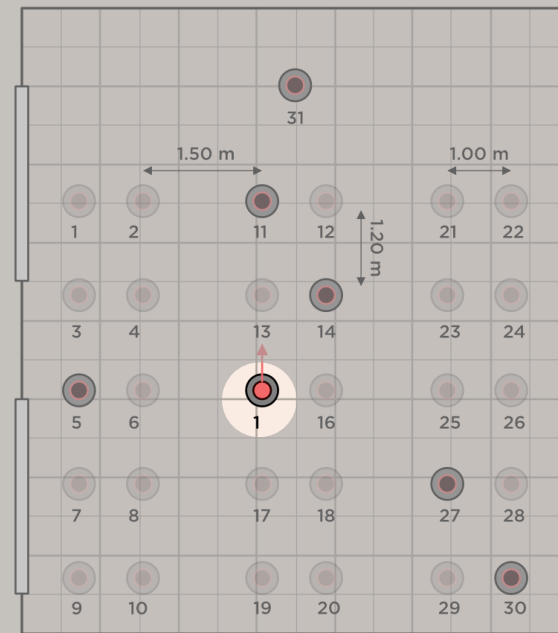
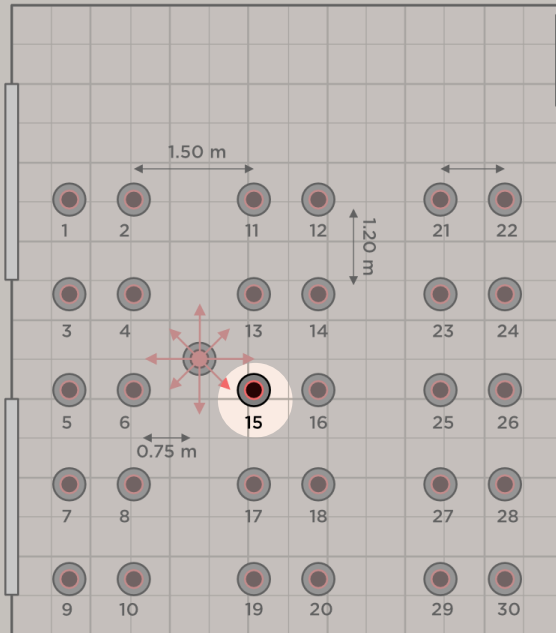
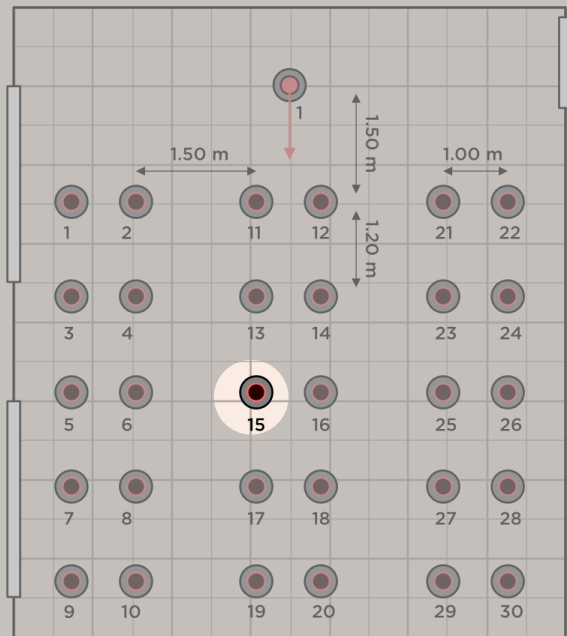
Simulation Model

10



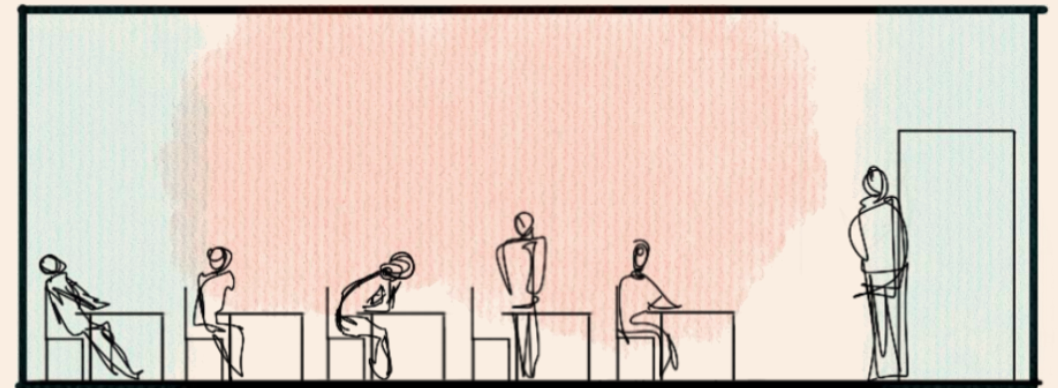
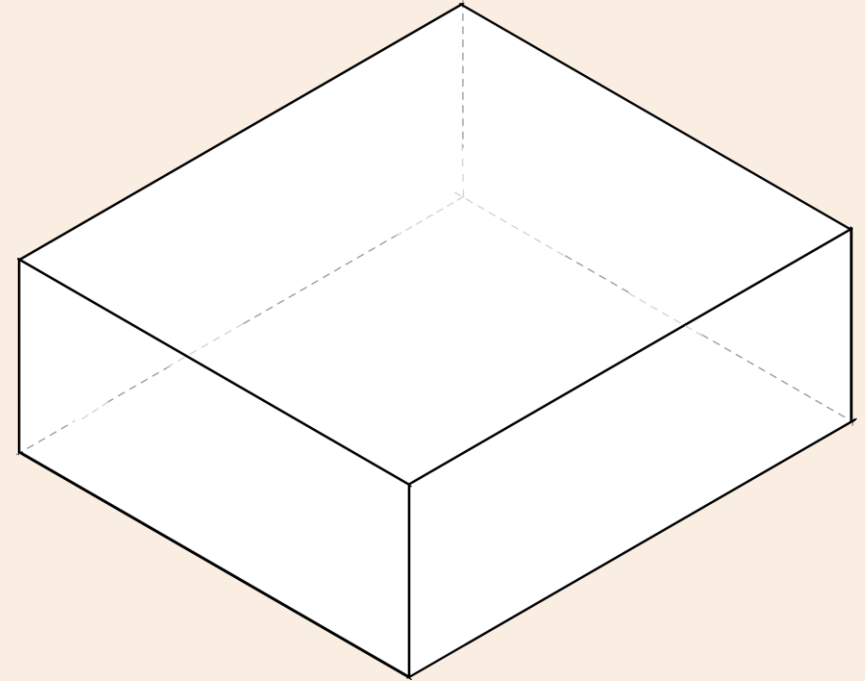
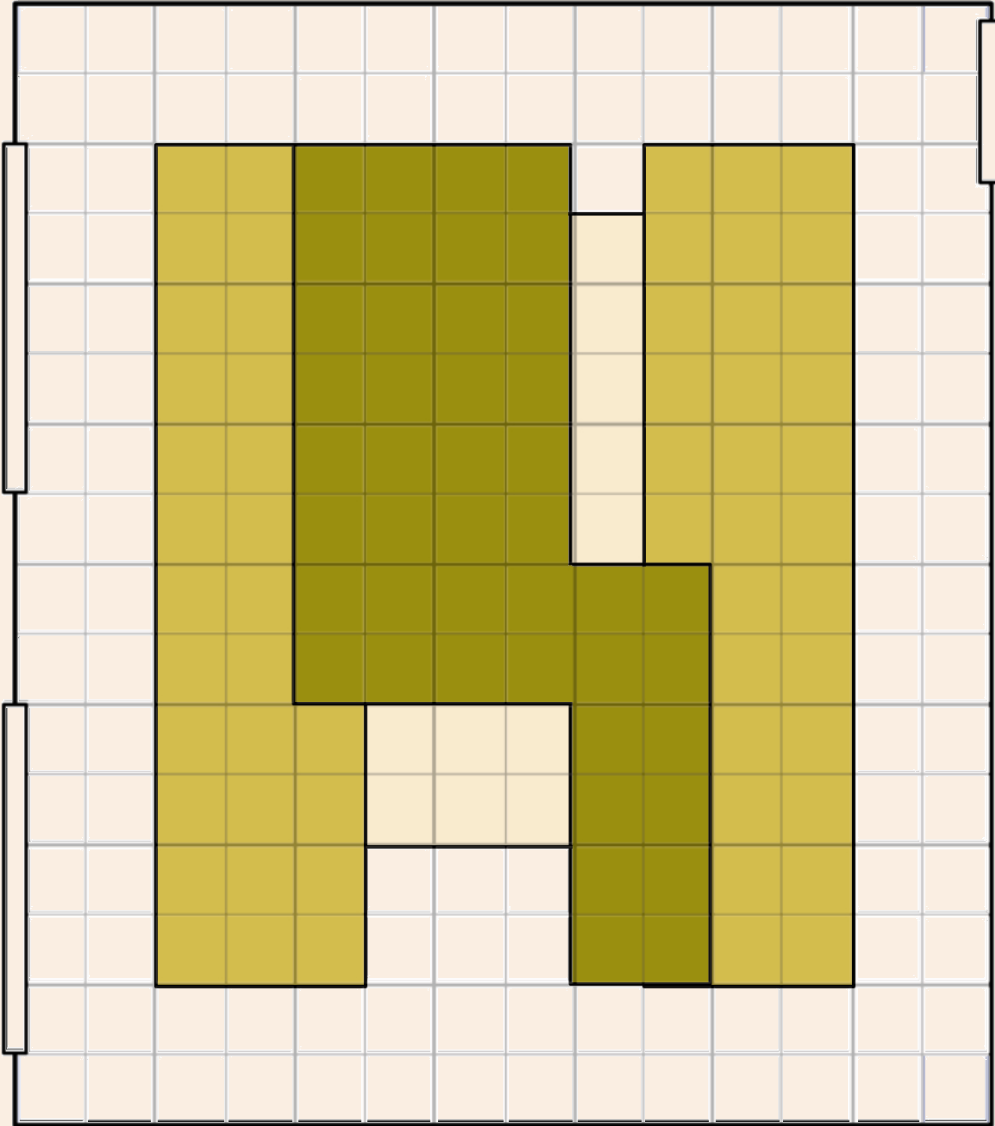
Ceilings

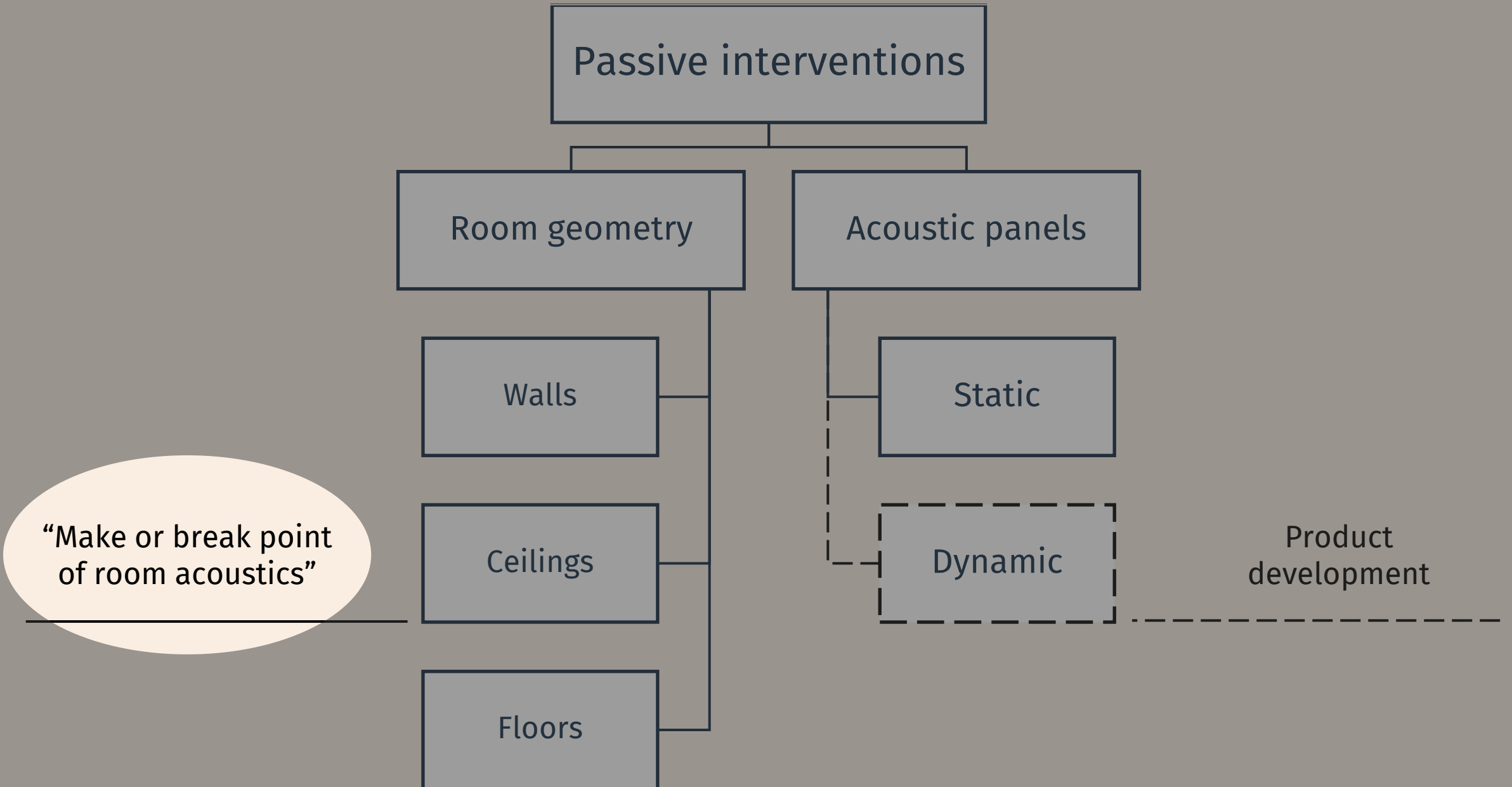
11



Flat Ceiling

12





Ceilings

Pitched

Inverted

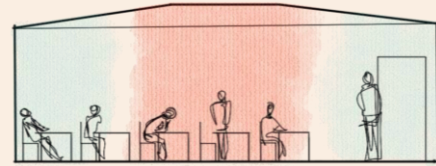
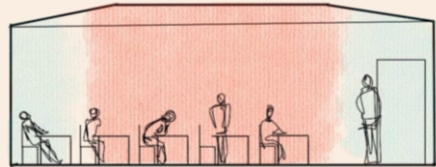
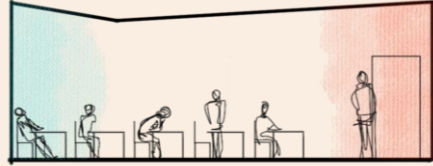
Hip

Convex

Concave

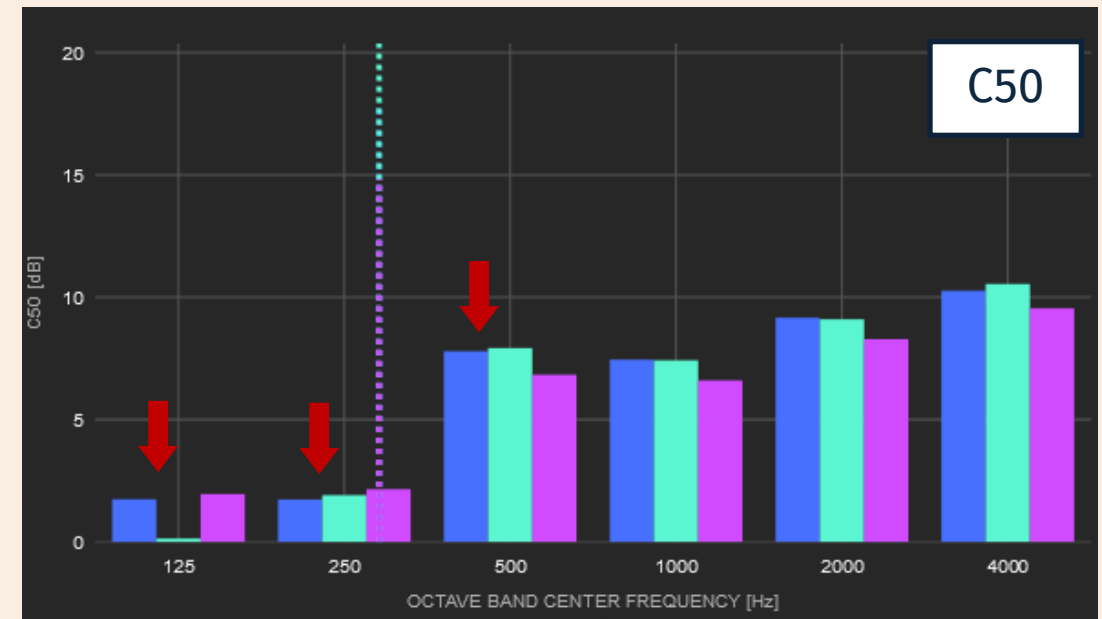
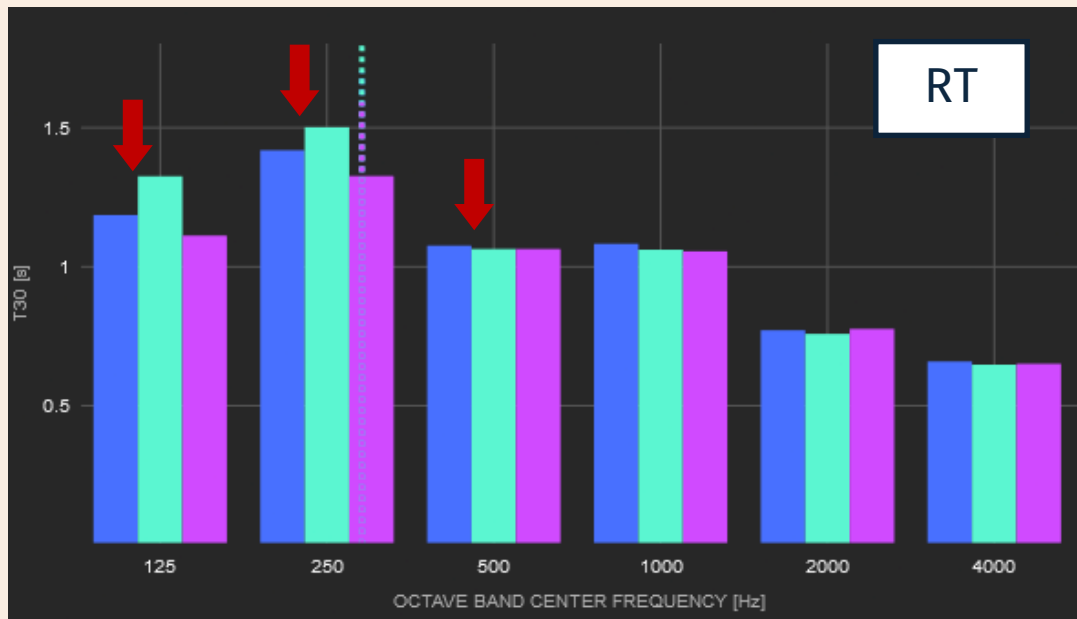
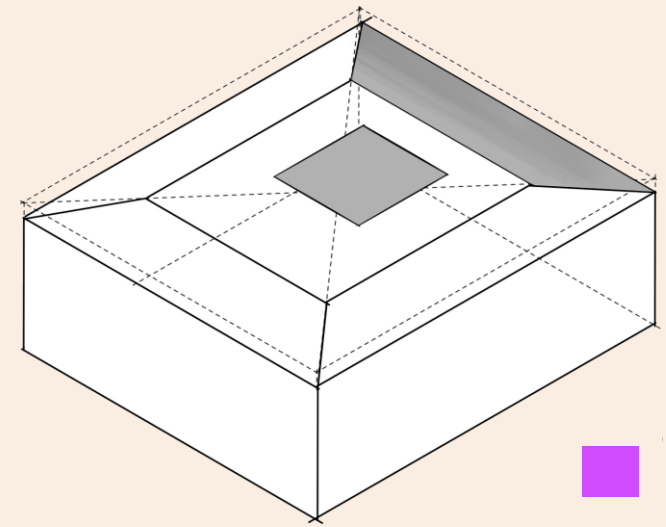
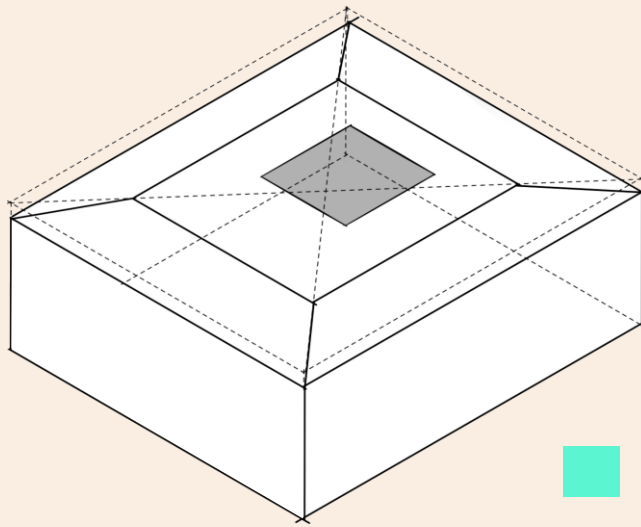
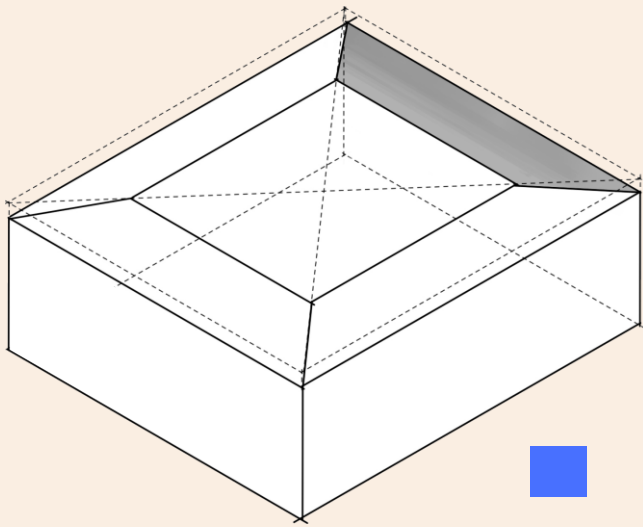
RT

C_{50}



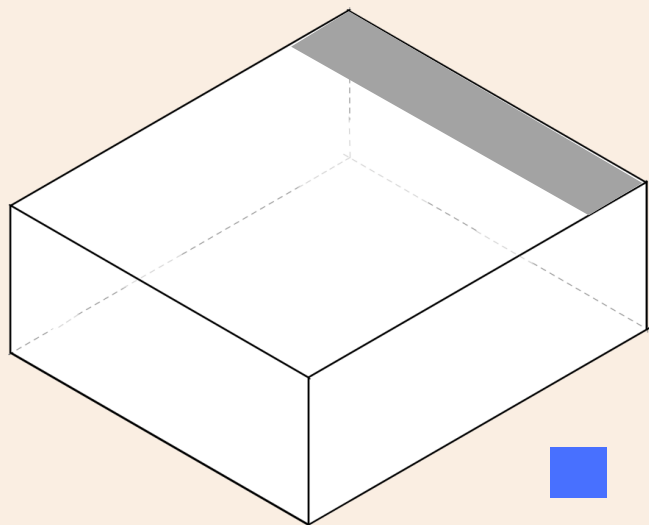
Ceilings

15

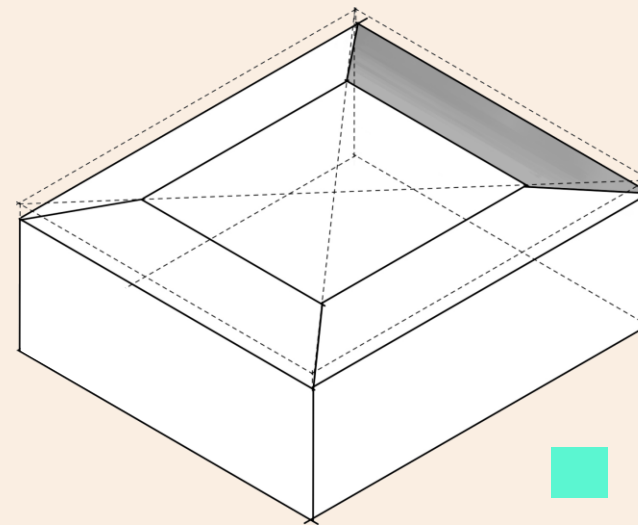


Ceilings

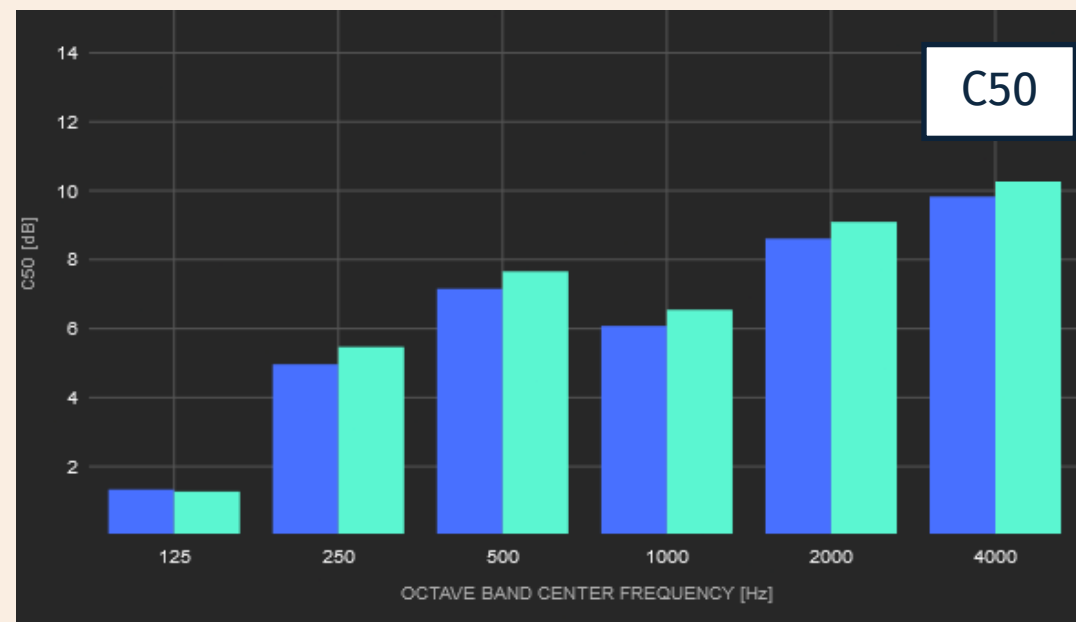
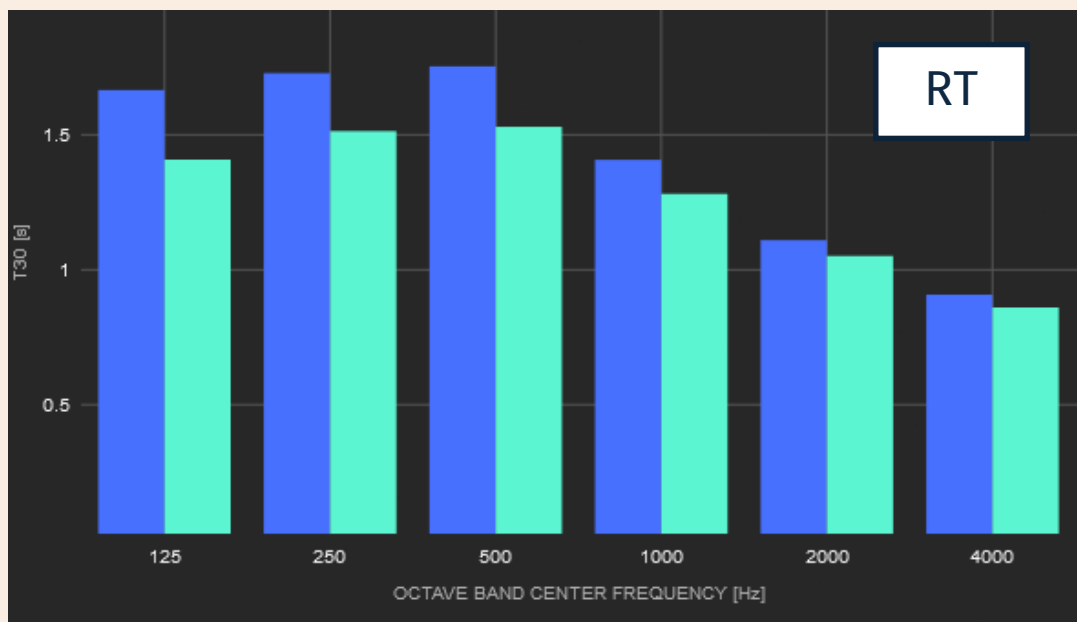
16

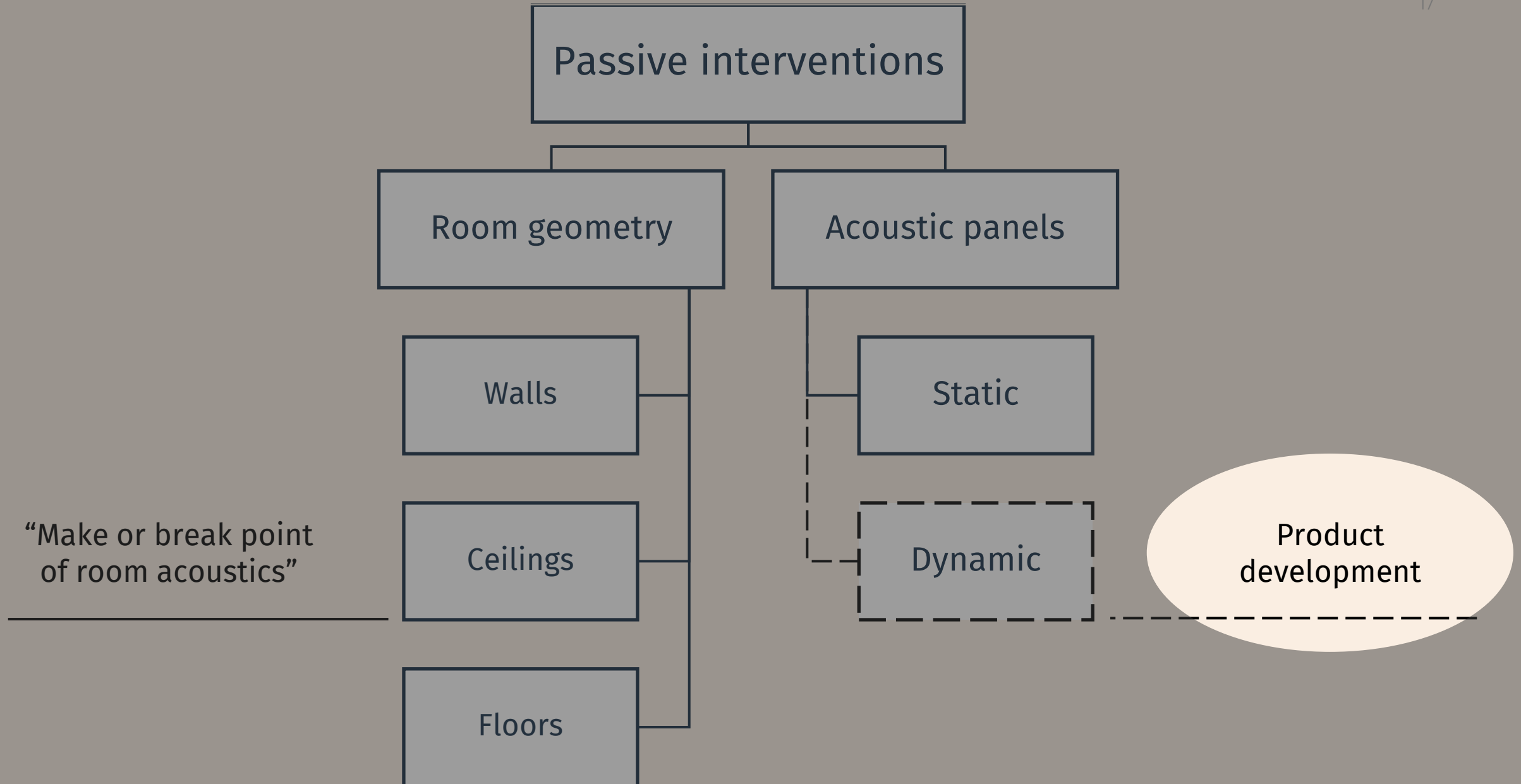


NRC Avg. RT: 1.29 s



NRC Avg. RT: 1.18 s





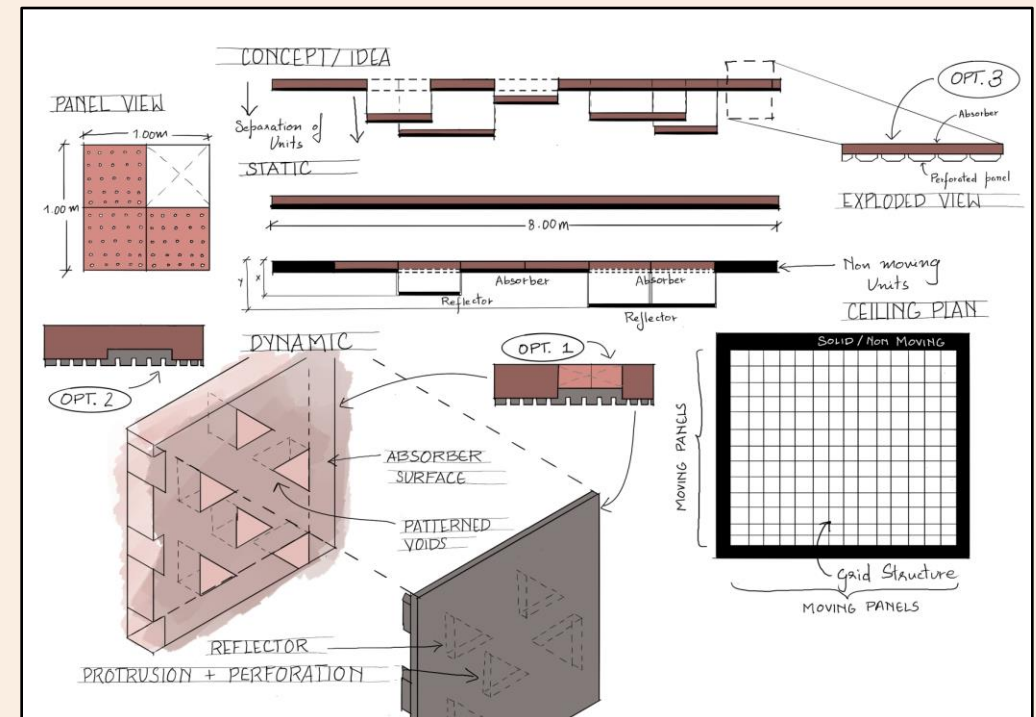
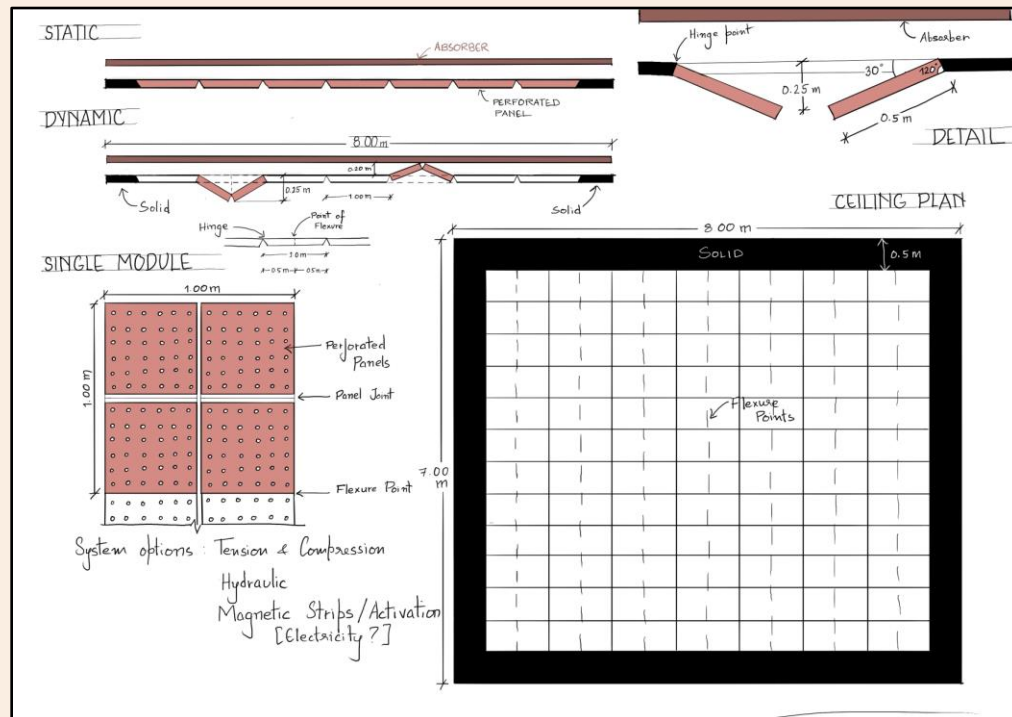
Types of Interventions

Absorber + Reflector
Combinations

Pre-existing
mechanism

Adjustable ceiling
geometries

Rotatable
geometries



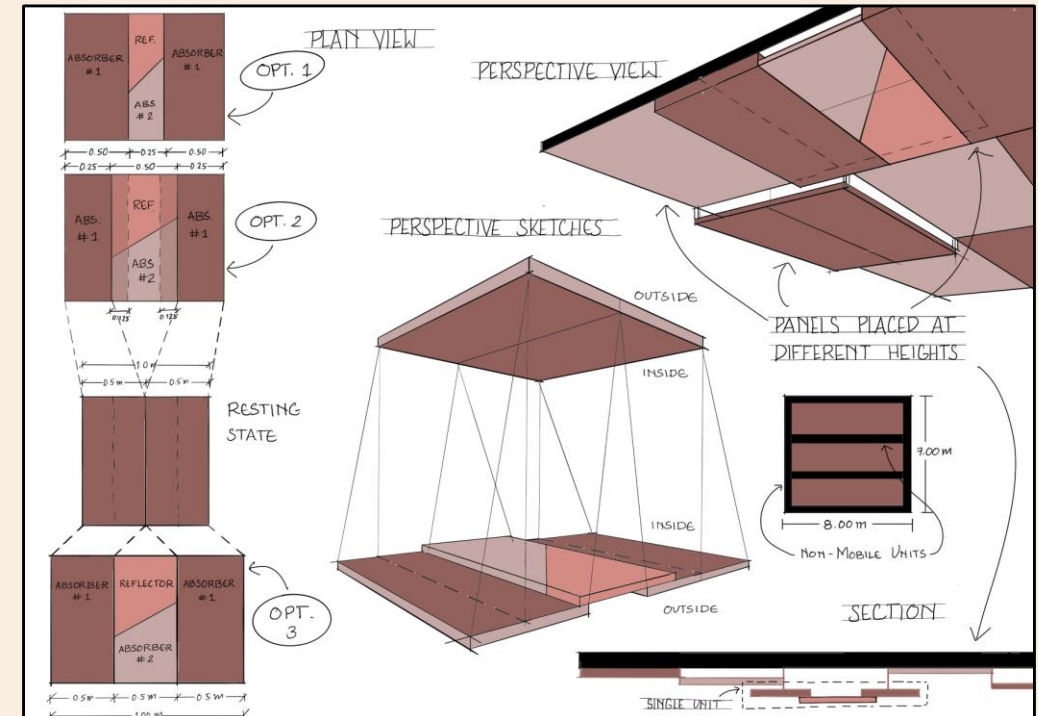
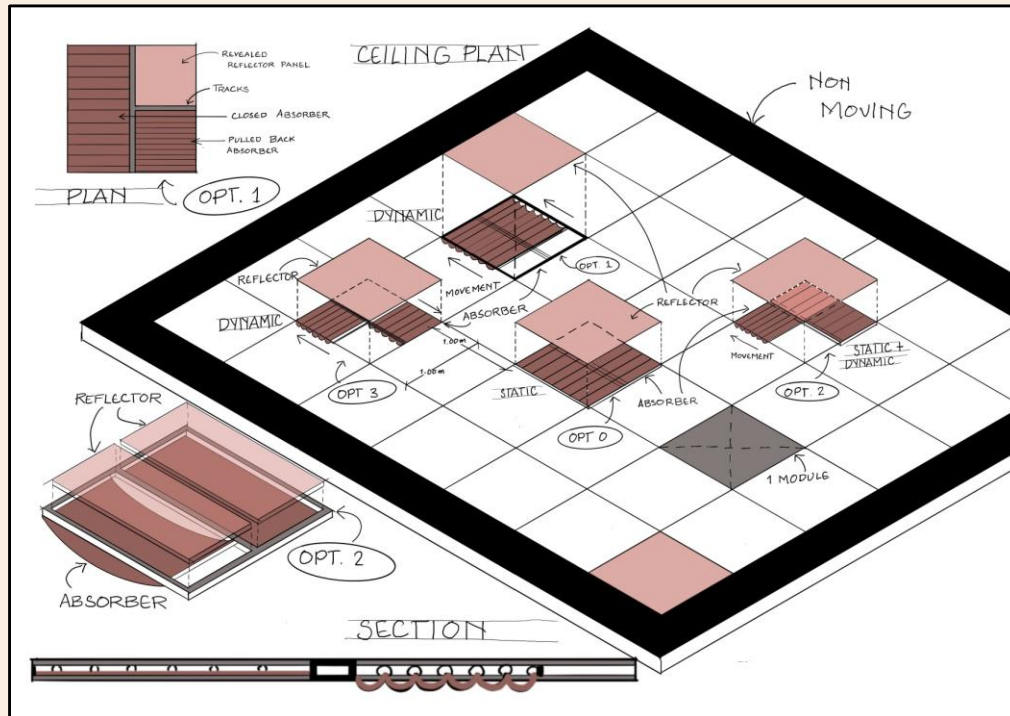
Types of Interventions

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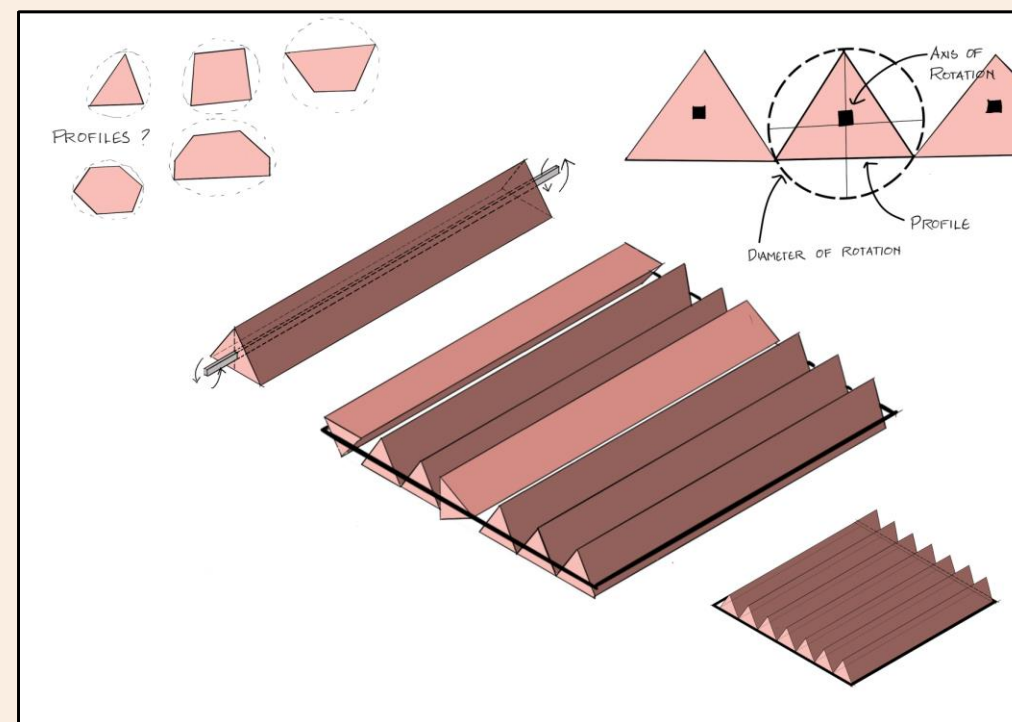
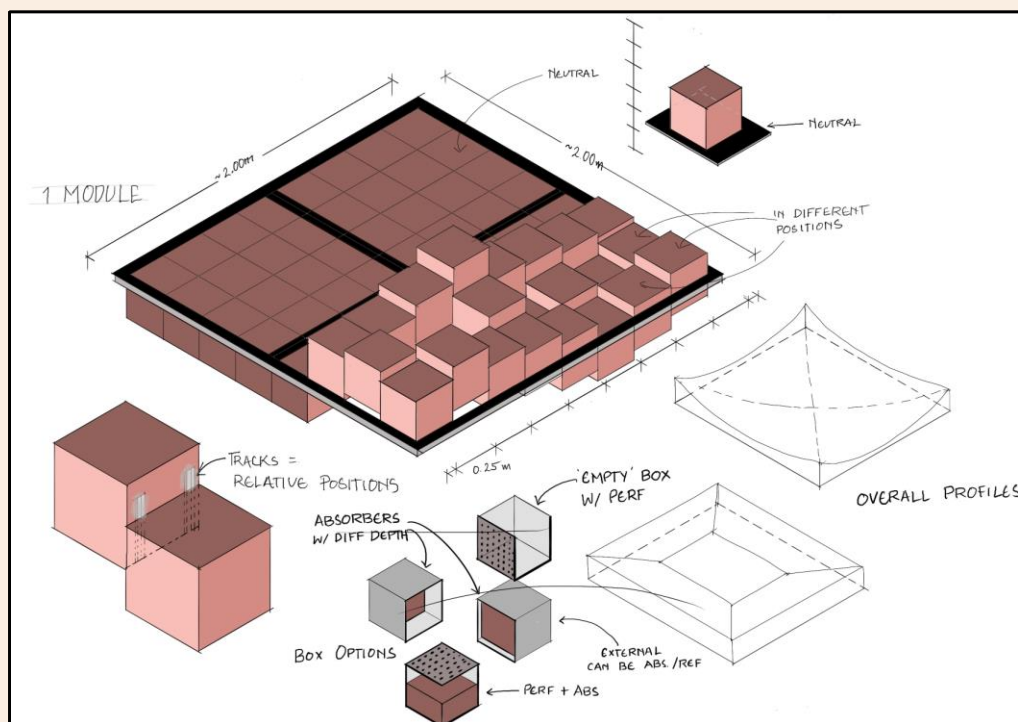
Types of Interventions

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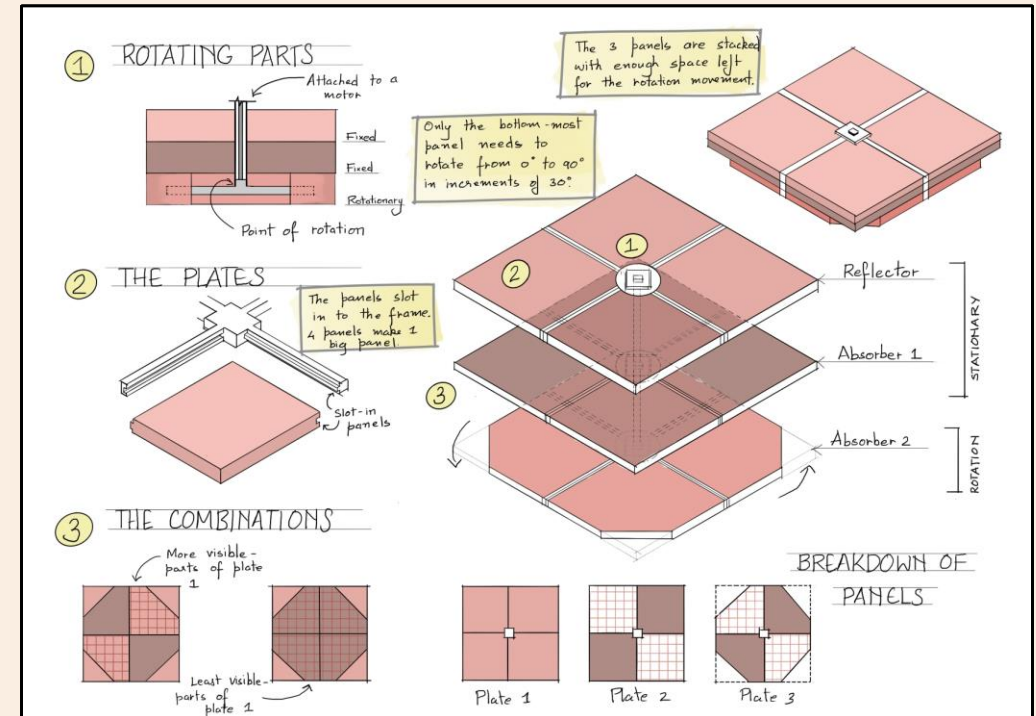
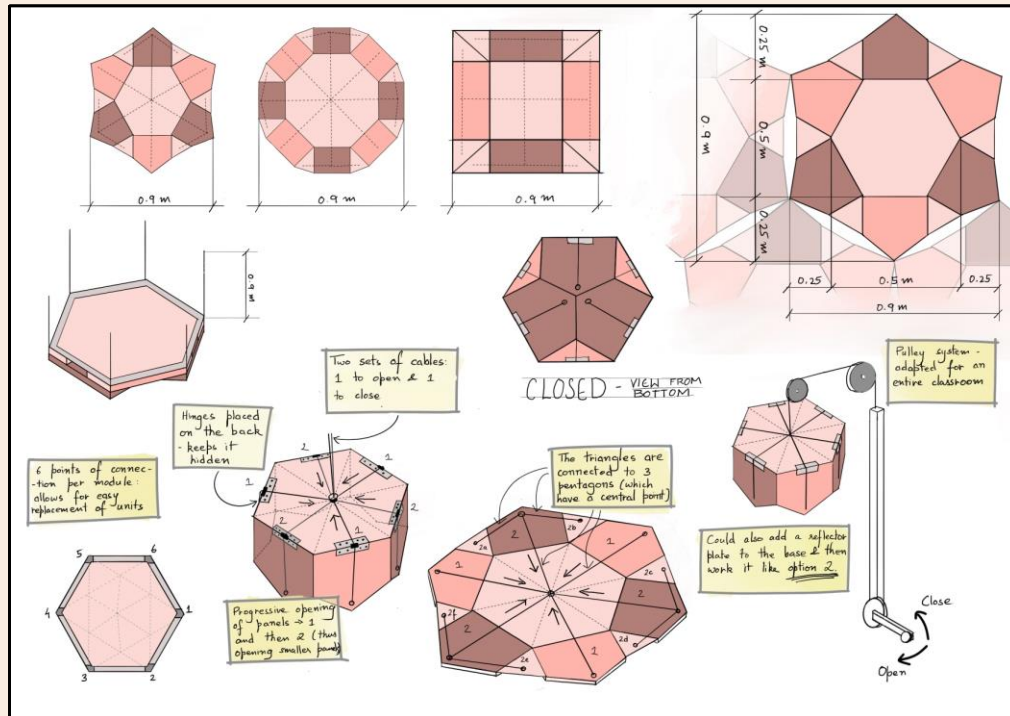
Types of Interventions

Absorber + Reflector
Combinations

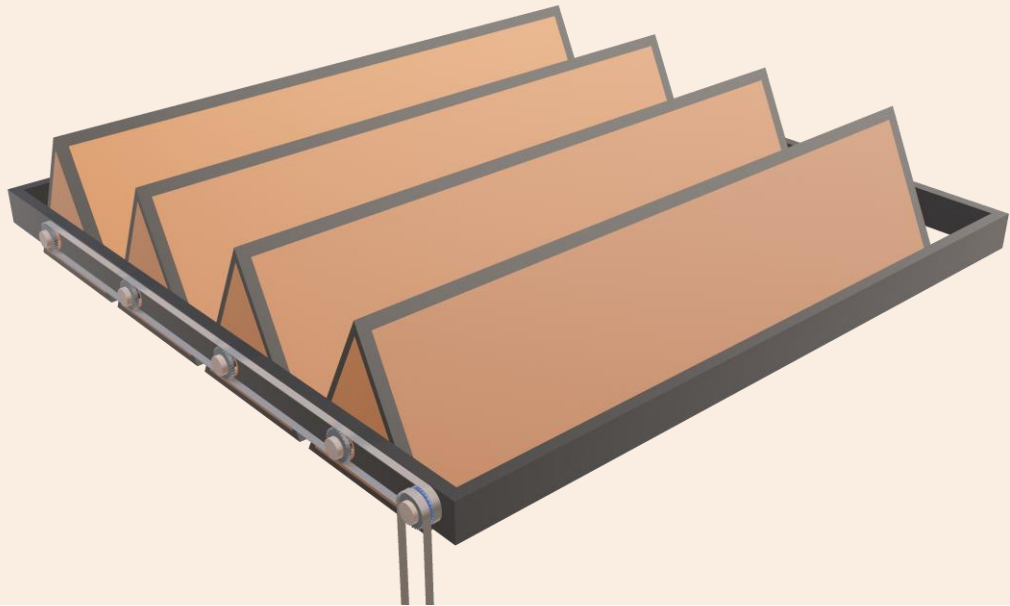
Pre-existing
mechanism

Adjustable ceiling
geometries

Rotatable
geometries



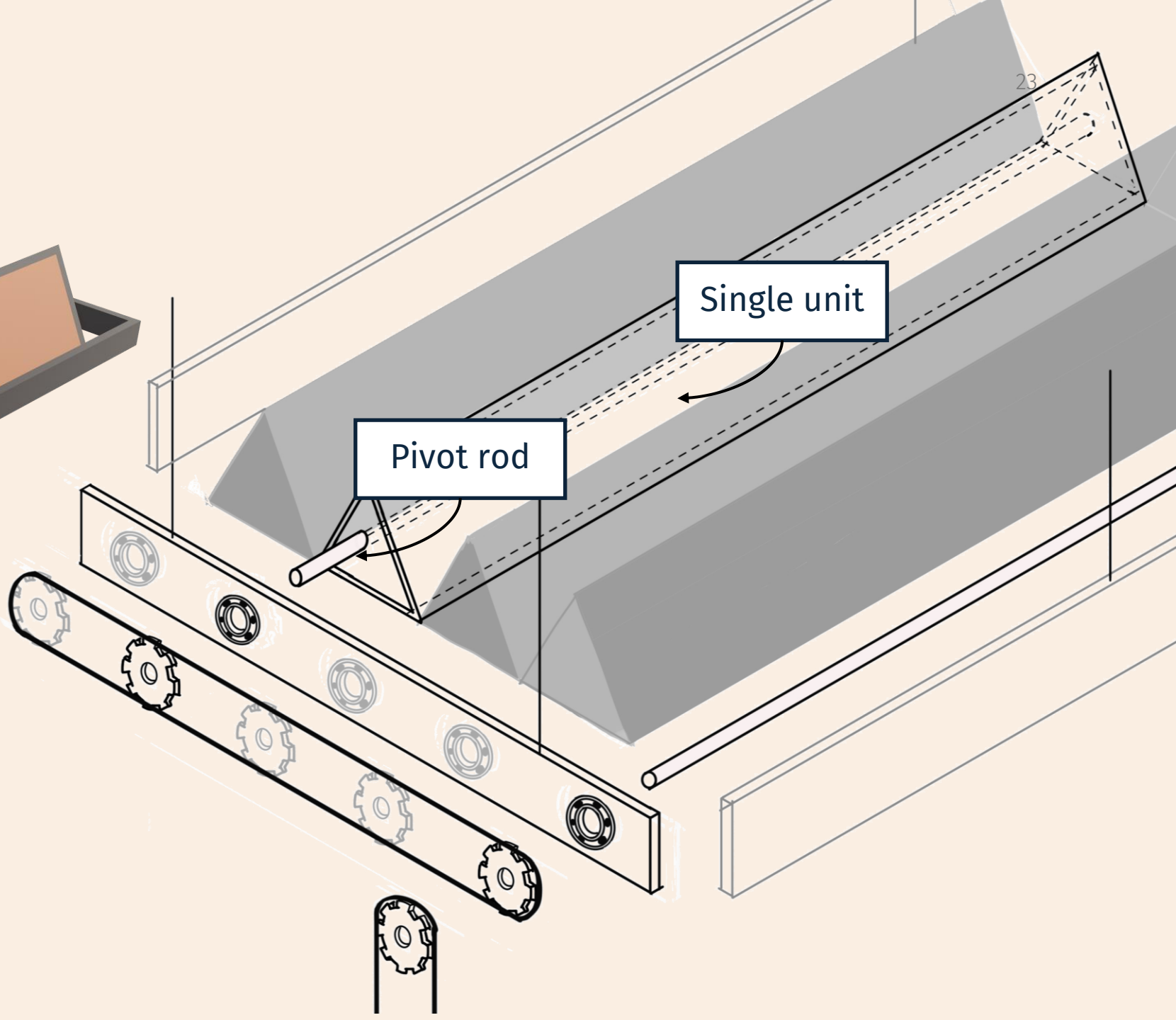
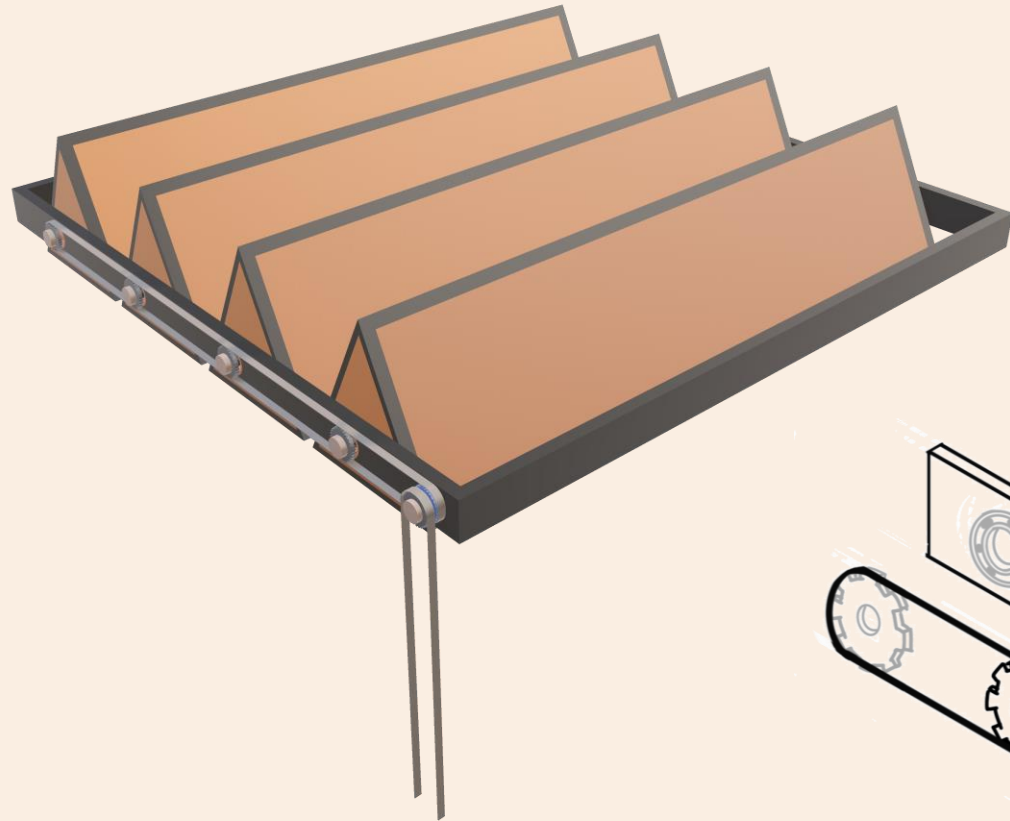
Dynamic Product



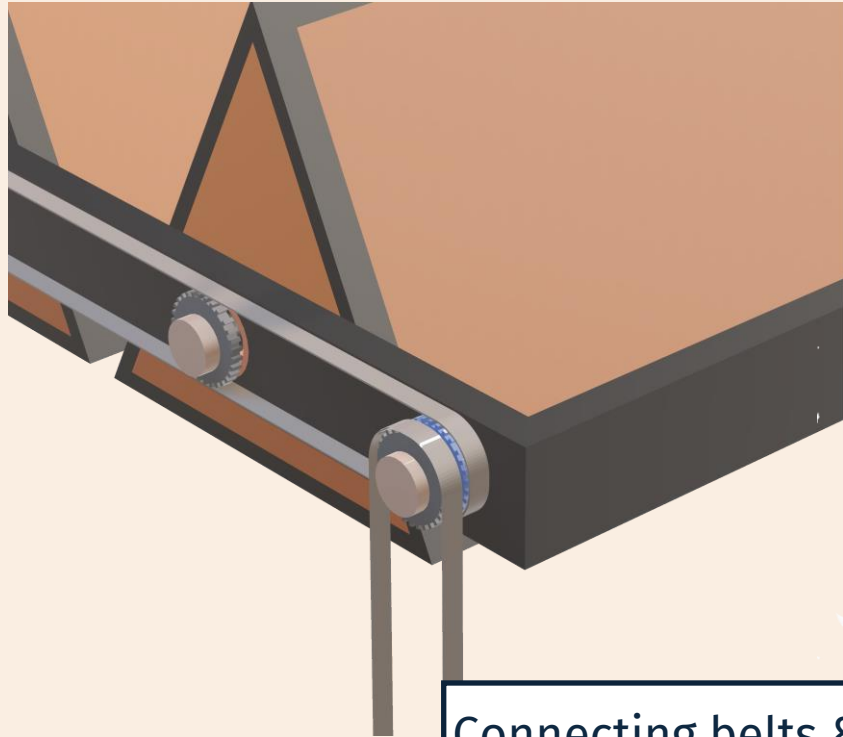
| Pre-Simulation | | | | | | | | | | | | | | | | | |
|----------------|------------|---------------|---------------|------------|-------------|-------------------|----------------------|------------------|---------------------------|---------------------------|------------------------|----------|---|---|---|----------------|---------------|
| Options | General | | | | | | | Acoustic Factors | | | | Scenario | | | | Kid Proof-ness | Overall Score |
| | Mechanics | Control Level | Configuration | Aesthetics | Module Size | Design Complexity | Mechanism Complexity | No. of Materials | Absorption 1 (per module) | Absorption 2 (per module) | Reflector (per module) | 1 | 2 | 3 | 4 | | |
| 1 | Hinge | 3 | Modules | 1 | 0.9 x 0.9 m | 1 | 4 | 2 | 1 sq. m. | n/a | 1 sq. m. | 4 | 1 | 4 | 4 | 3 | 🔴 2.86 |
| 2 | Push/Pull | 3 | | 2 | | 3 | 5 | 2 | 1 sq. m. | n/a | 1 sq. m. | 2 | 3 | 3 | 4 | 3 | 🔴 2.86 |
| 3 | Push/Pull | 3 | | 3 | | 4 | 4 | 2 | 1 sq. m. | n/a | 0.5 - 0.8 sq. m. | 2 | 3 | 3 | 4 | 4 | 🟡 3.14 |
| 4 | Push/Pull | 4 | | 4 | | 3 | 3 | 2 - 3 | 1 sq. m. | n/a | 0.5 sq. m. | 3 | 4 | 3 | 4 | 5 | 🟡 3.86 |
| 5 | Push/Pull | 4 | | 3 | | 2 | 3 | 2 | 0.5 - 1 sq. m. | 0.5 sq. m. | 0.5 sq. m. | 3 | 2 | 3 | 3 | 3 | 🟡 3 |
| 6 | Push/Pull | 5 | | 5 | | 5 | 5 | 3+ | 1 sq. m. | 1+ sq. m. | 1+ sq. m. | 4 | 4 | 4 | 5 | 5 | ✅ 4.57 |
| 7 | Rotation | 5 | | 4 | | 2 | 4 | 3 | 1 sq. m. | 1 sq. m. | 1 sq. m. | 5 | 4 | 4 | 4 | 5 | ✅ 4.25 |
| 8 | Sliding | 2 | | 2 | | 1 | 4 | 1 | n/a | n/a | n/a | 2 | 1 | 1 | 1 | 4 | 🔴 1.86 |
| 9 | Rotation | 3 | | 2 | | 1 | 5 | 3 | 0.5 sq. m. | 0.5 sq. m. | 1 sq. m. | 3 | 2 | 2 | 3 | 5 | 🔴 2.88 |
| 10 | Push/Pull | 4 | | 4 | | 4 | 5 | 2 - 3 | n/a | n/a | n/a | 4 | 3 | 4 | 5 | 2 | 🟡 3.71 |
| 11 | Deployment | 4 | | 4 | | 5 | 2 | 2 | n/a | n/a | n/a | 3 | 3 | 3 | 3 | 3 | 🟡 3.29 |



Dynamic Product



Dynamic Product



Connecting belts & gears

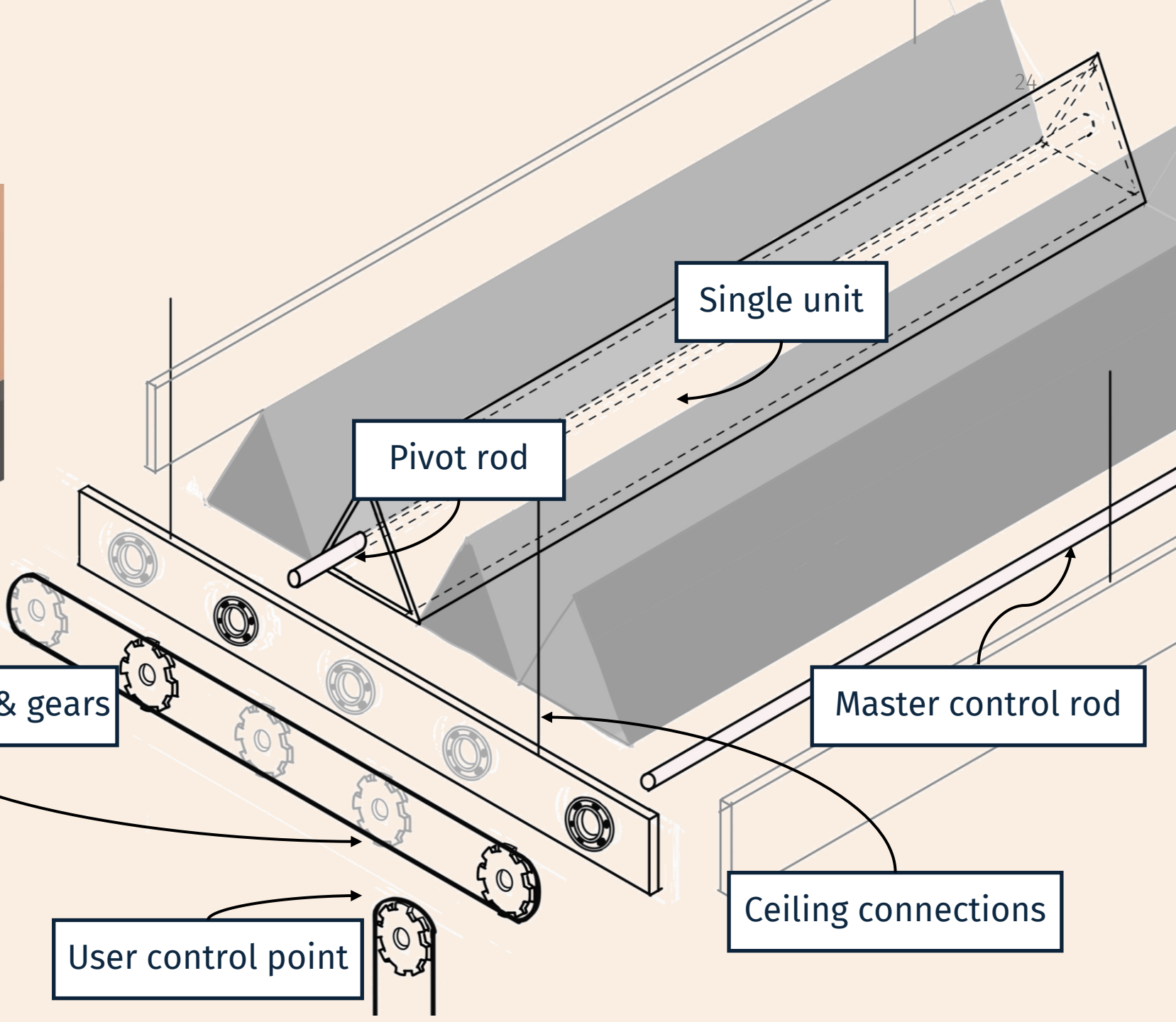
User control point

Pivot rod

Single unit

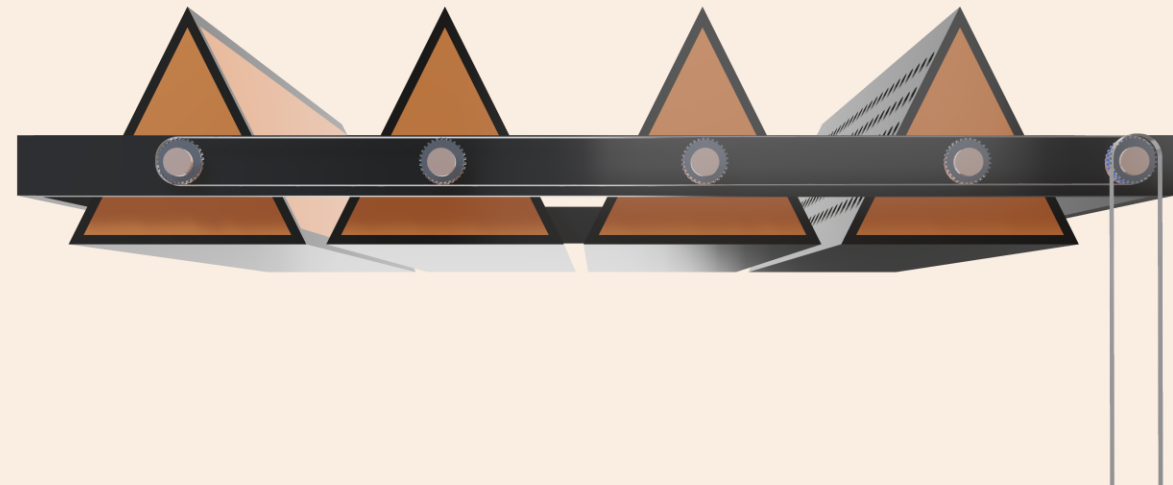
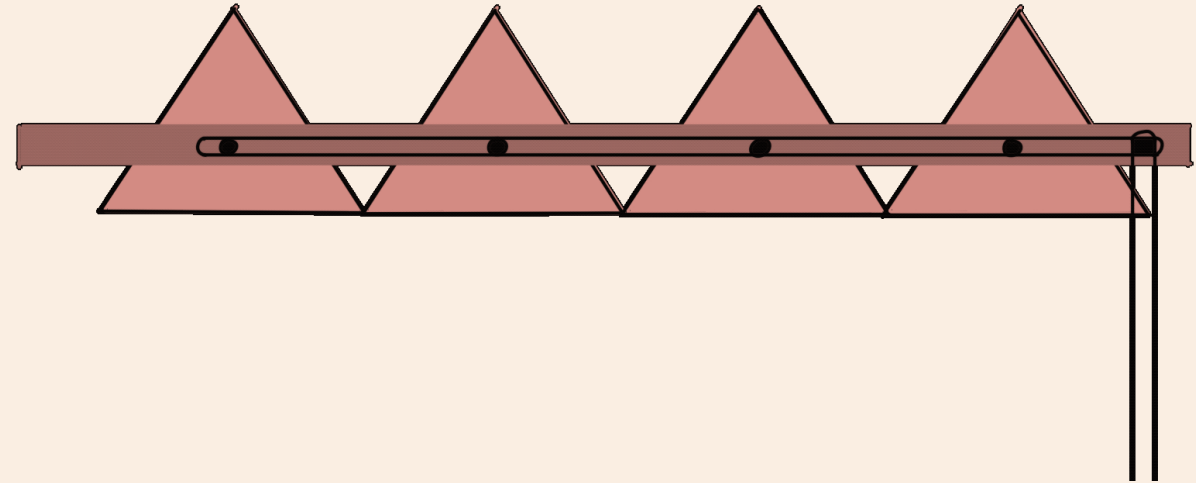
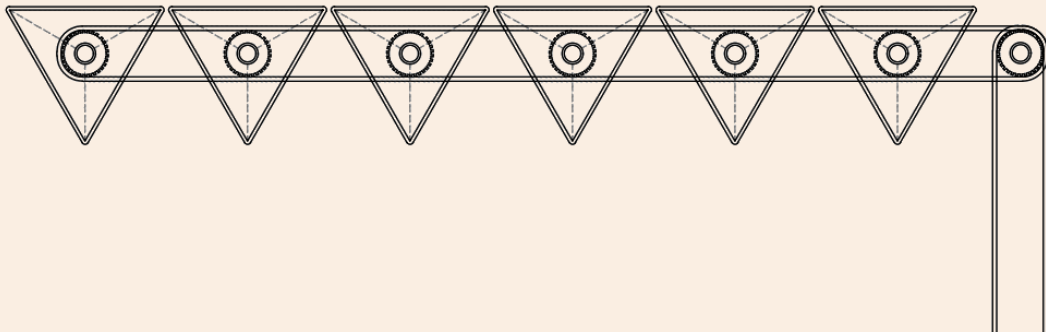
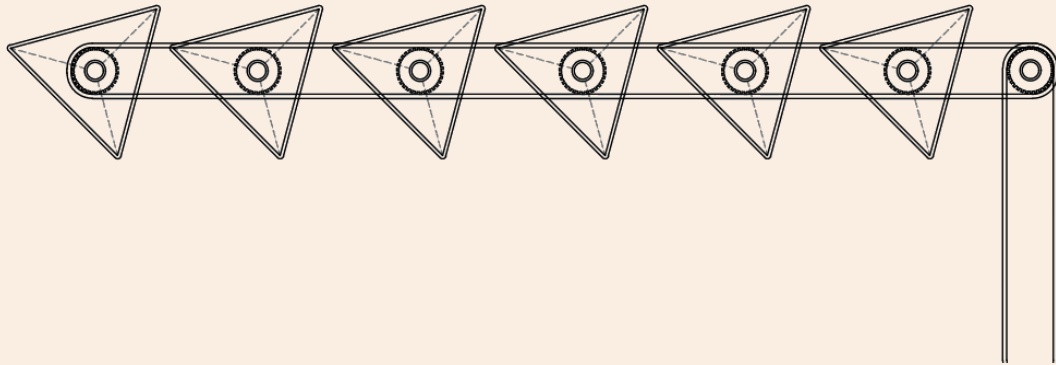
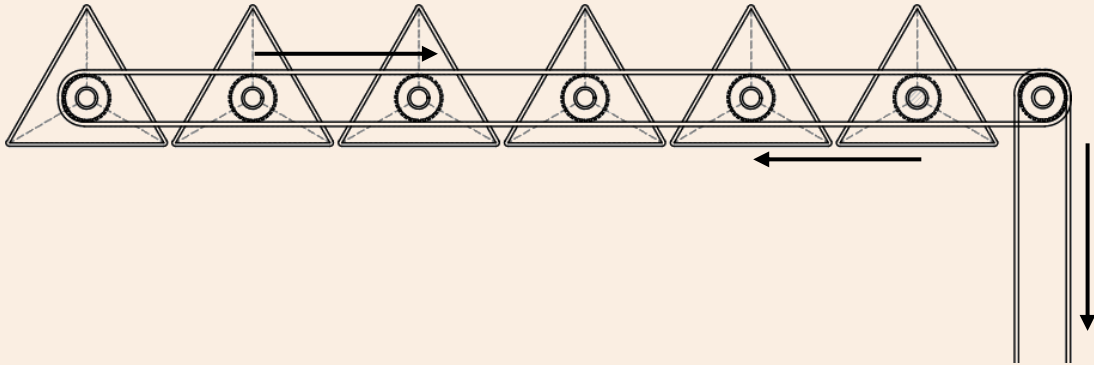
Master control rod

Ceiling connections



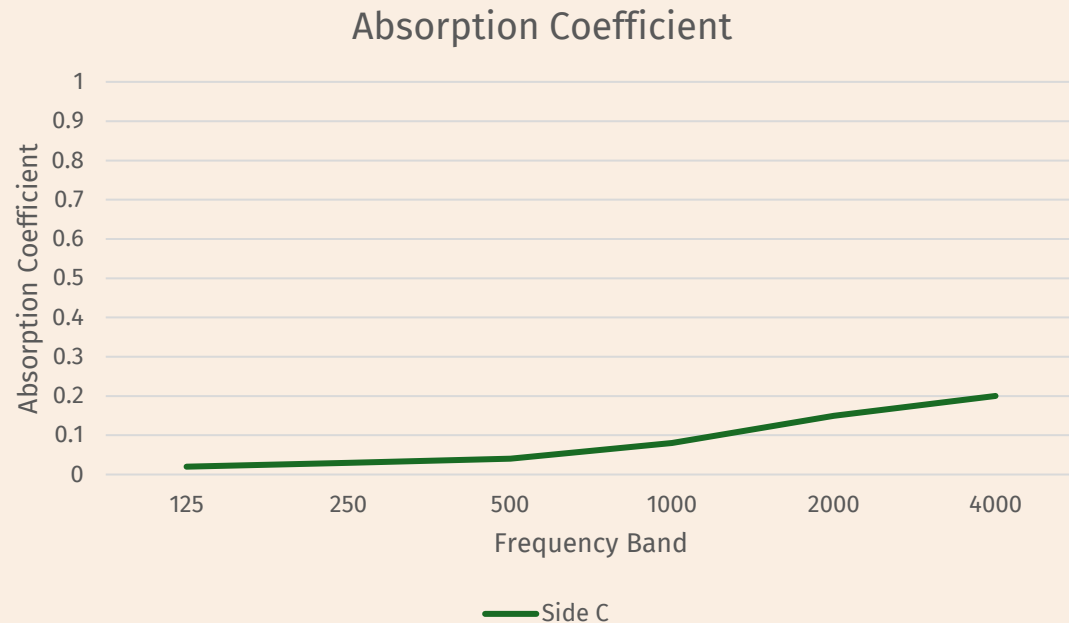
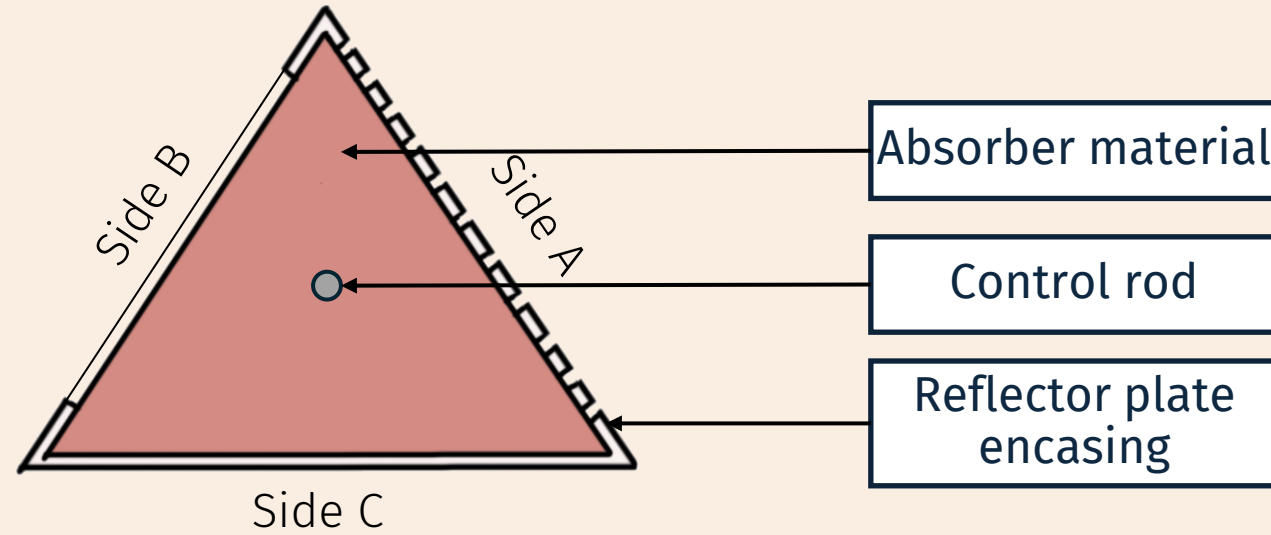
Dynamic Product

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Dynamic Product

26

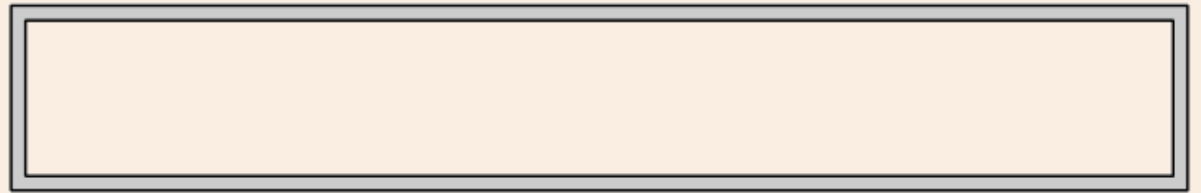
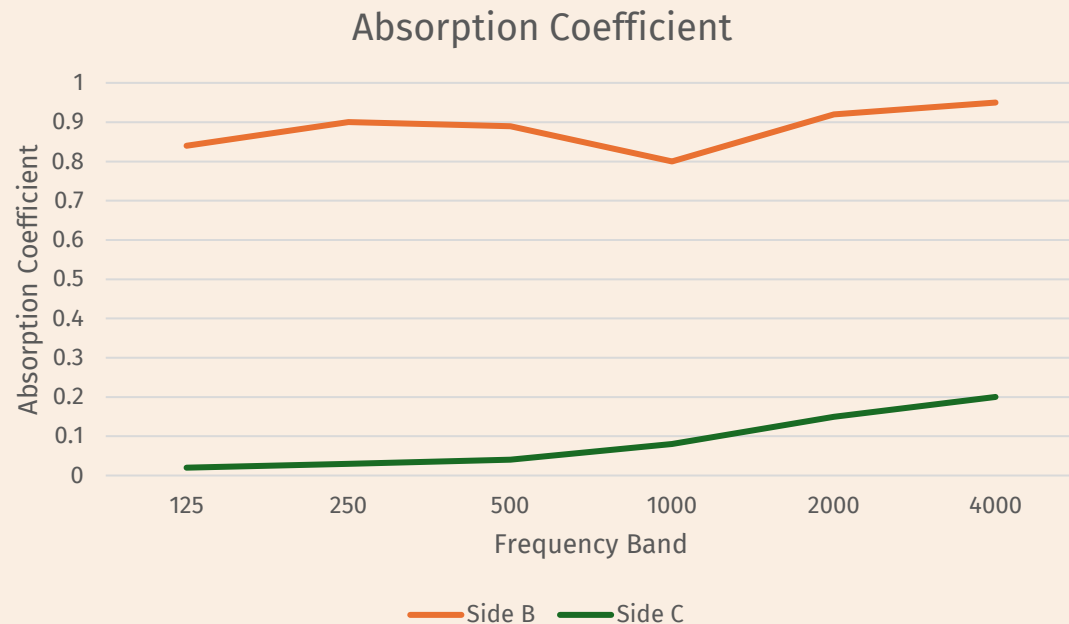
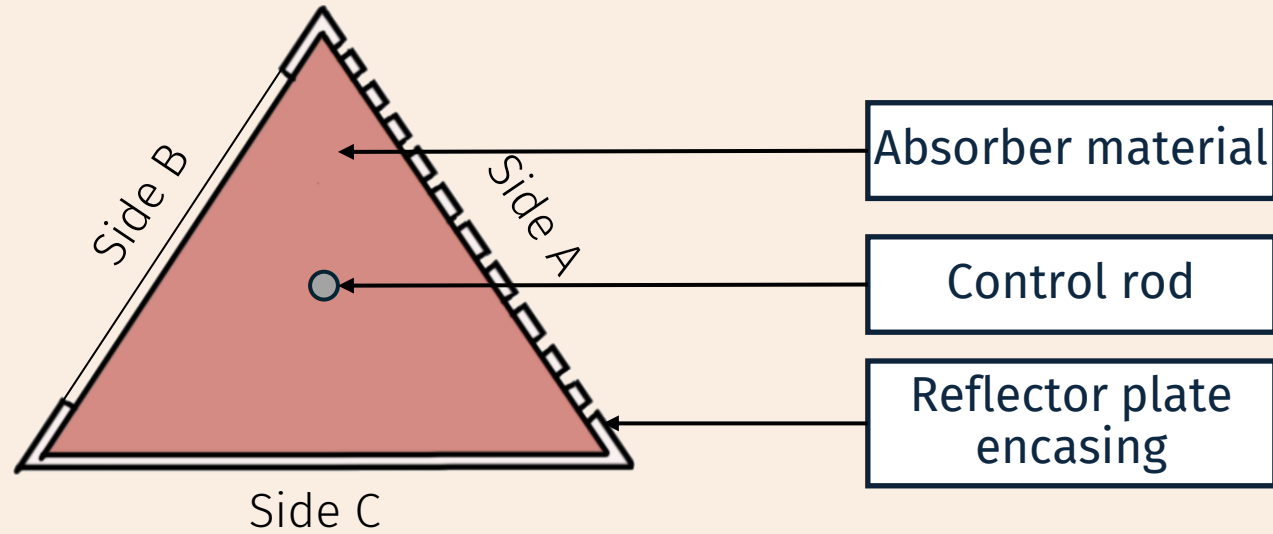


Side C

- NRC: 0.075
- Behaviour: Reflector

Dynamic Product

27

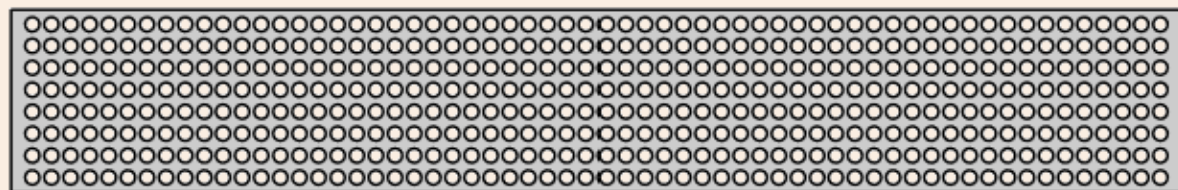
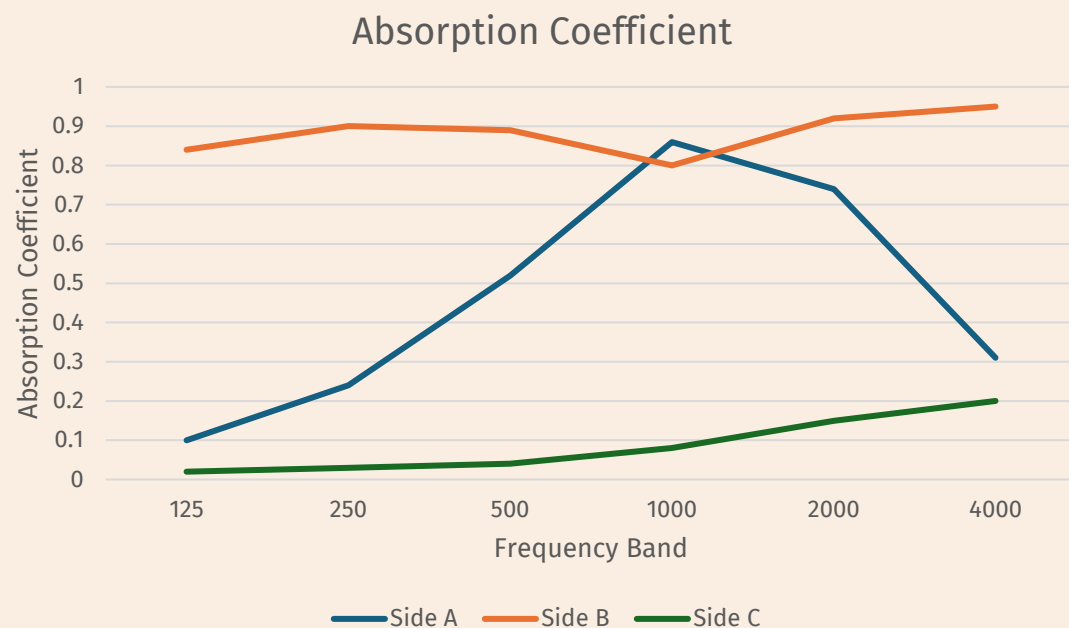
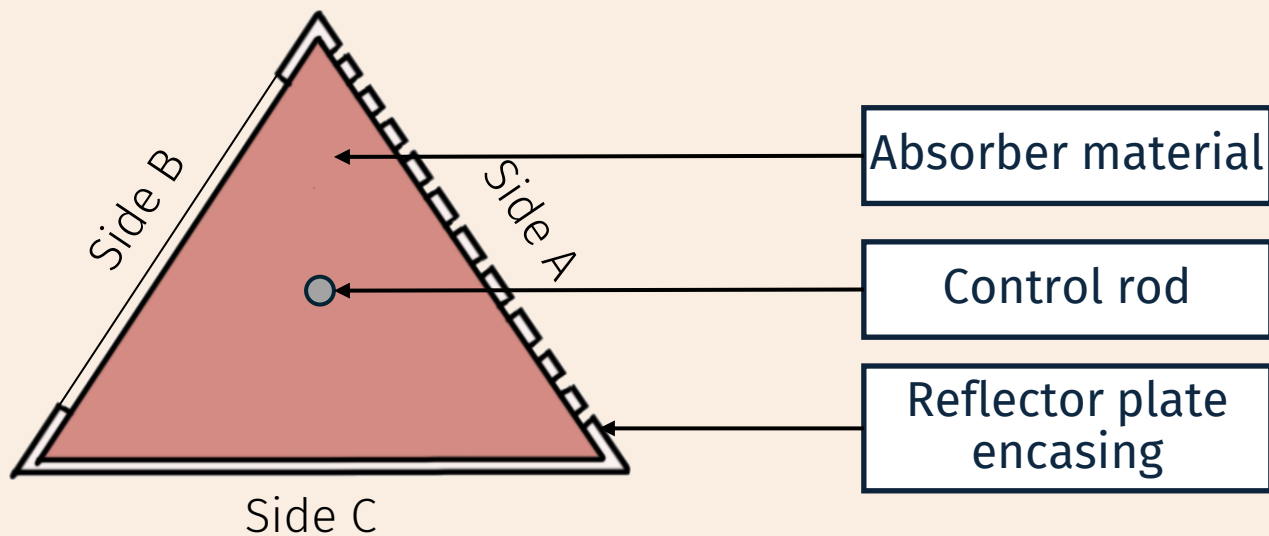


Side B

- NRC: 0.89
- Behaviour: Absorber

Dynamic Product

28

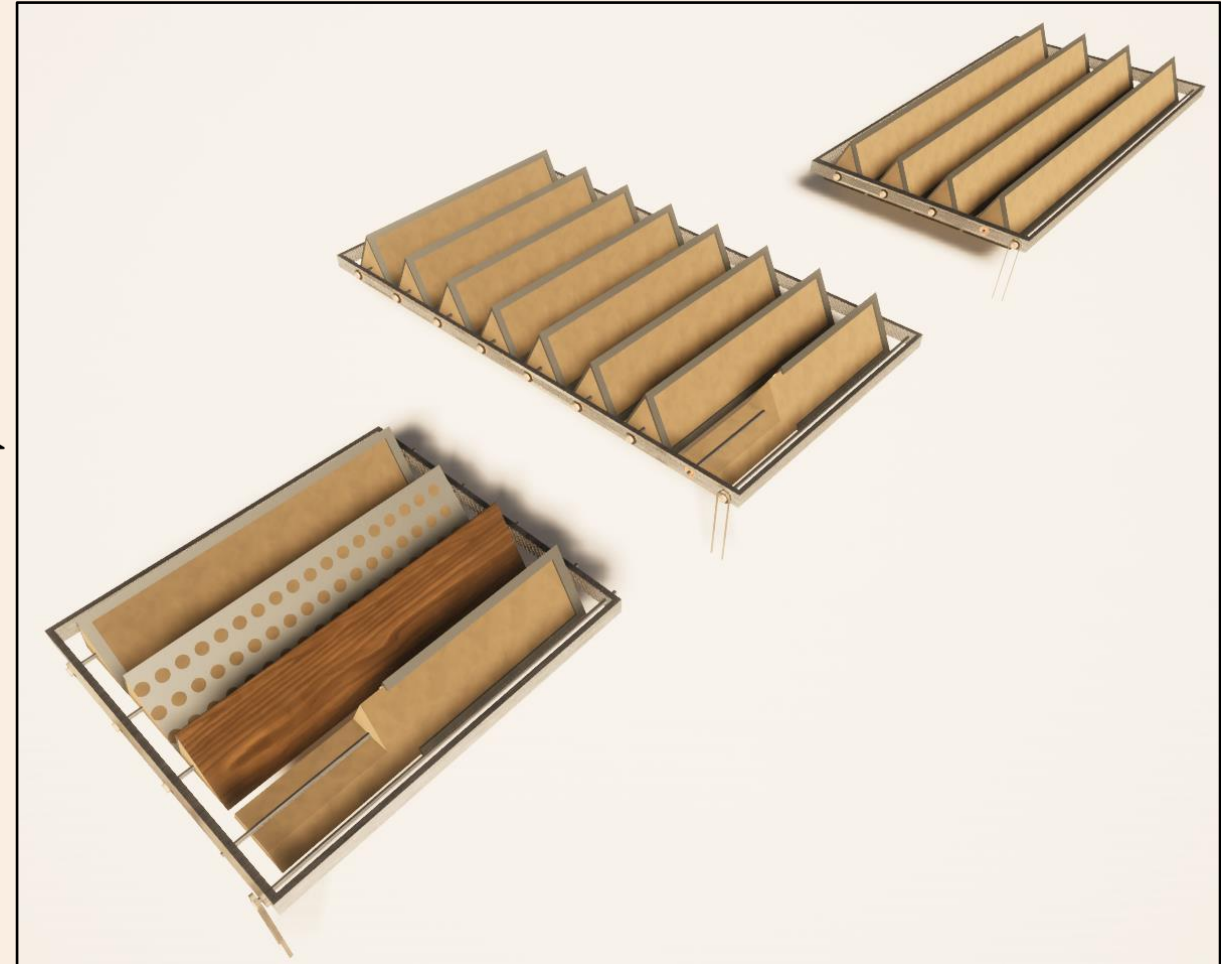
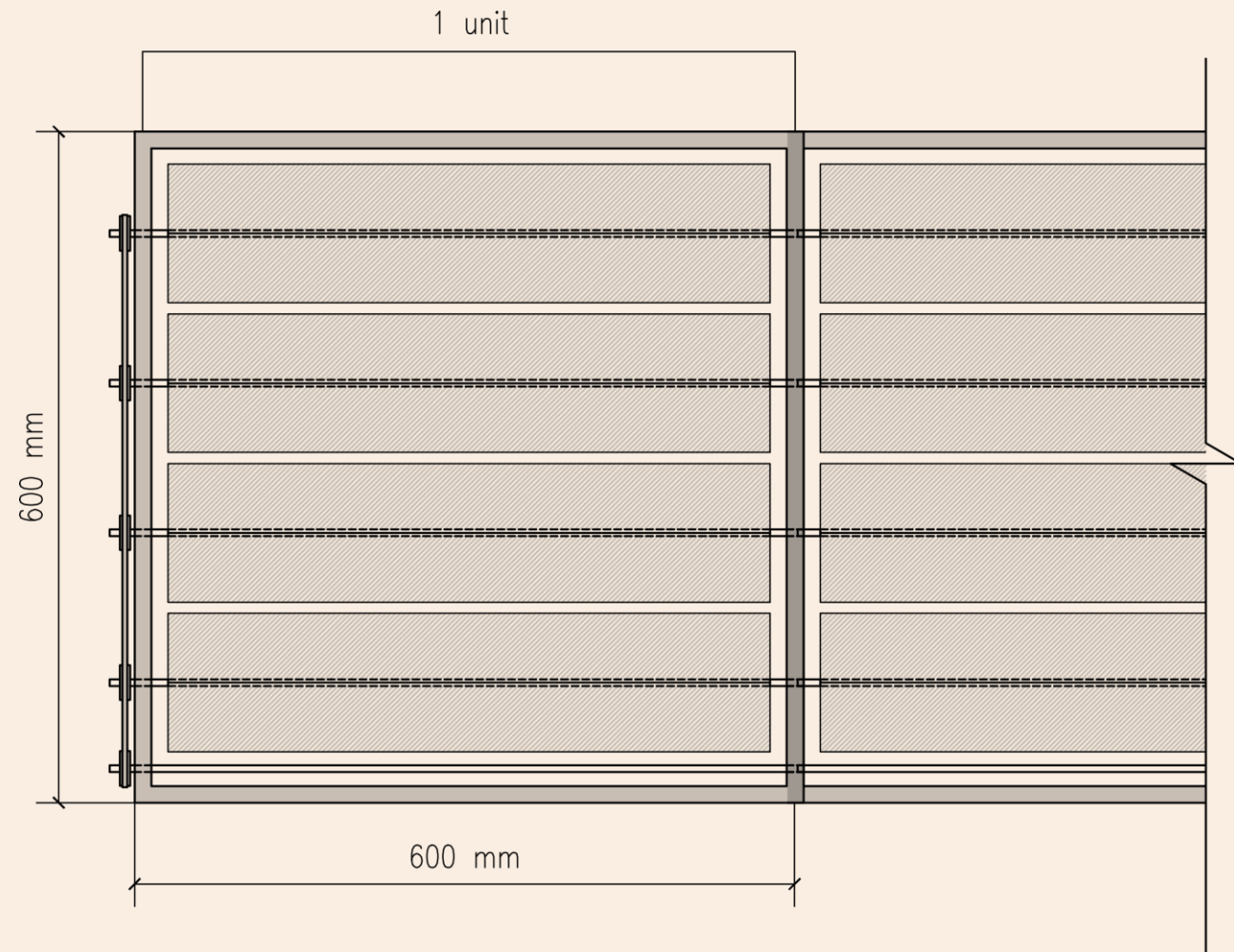


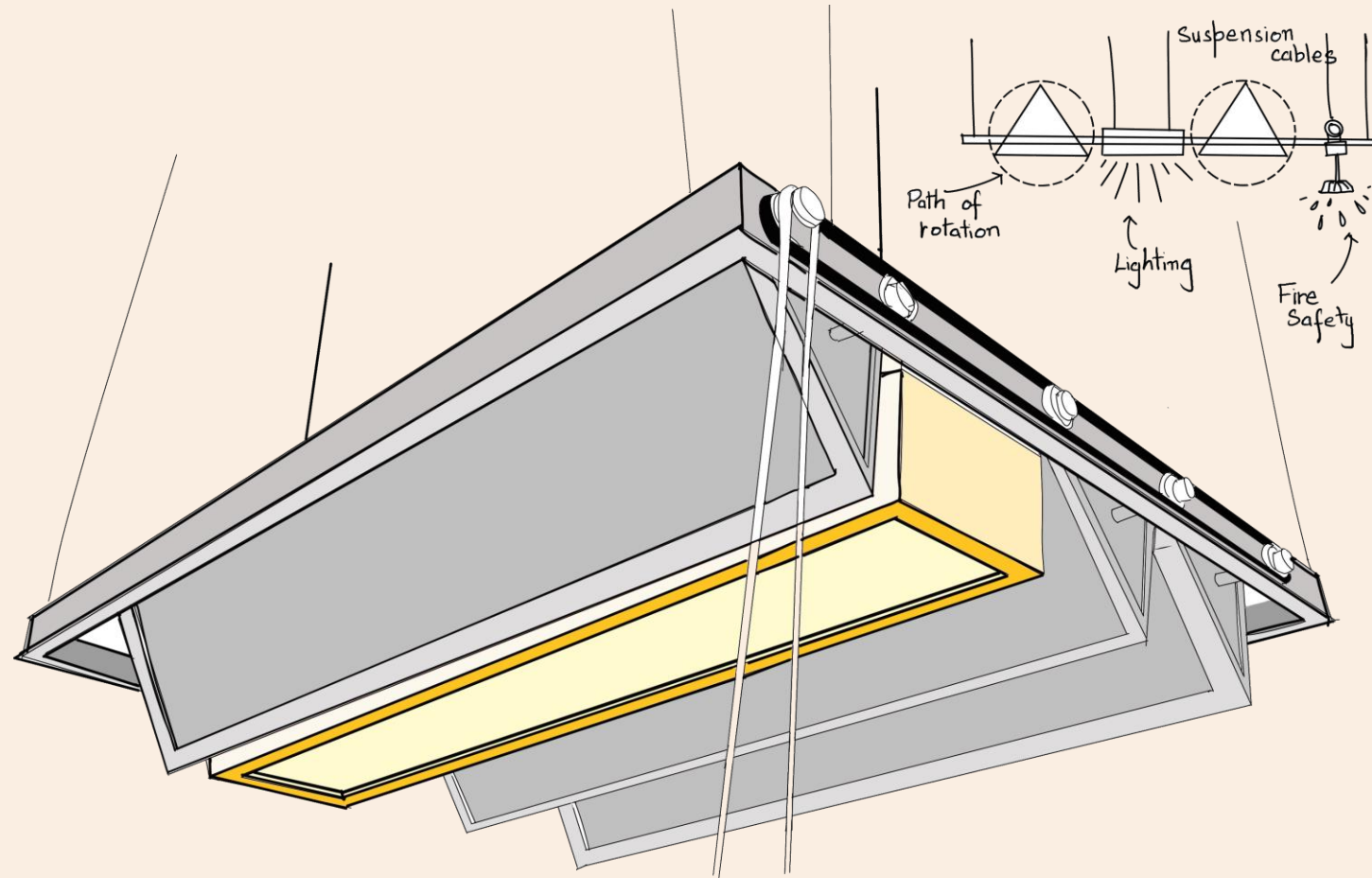
Side A

- NRC: 0.59
- Behaviour: Absorber

Dynamic Product

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Integrated Design



Integrated Design

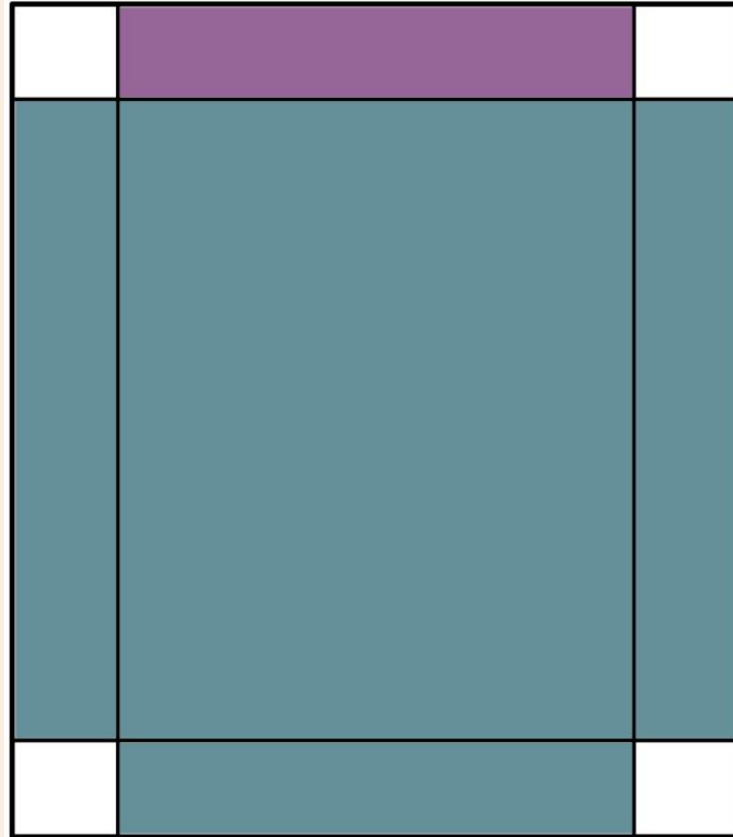


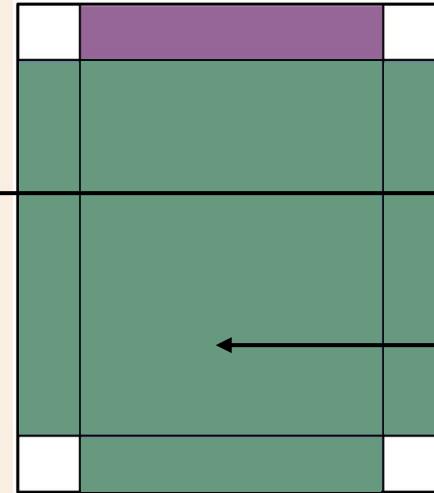
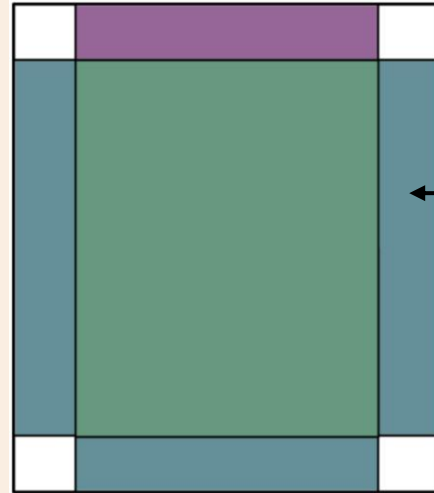
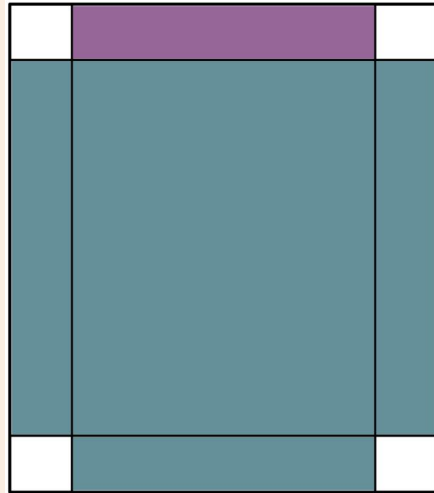
Integrated Design



Integrated Design

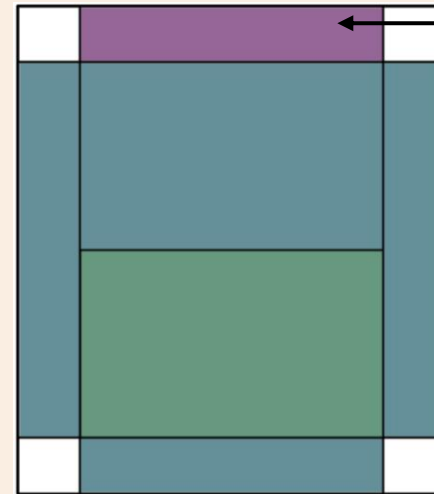
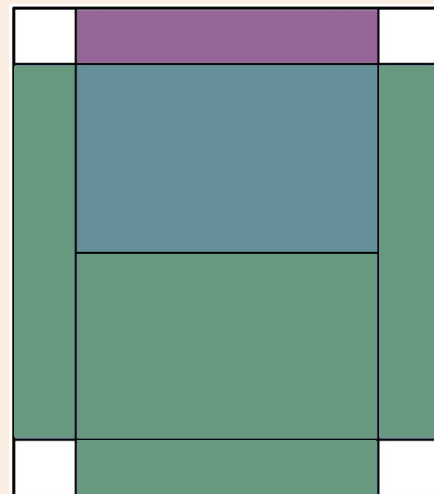
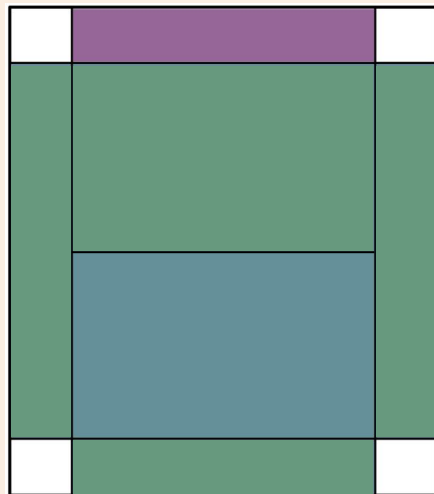






Absorbers

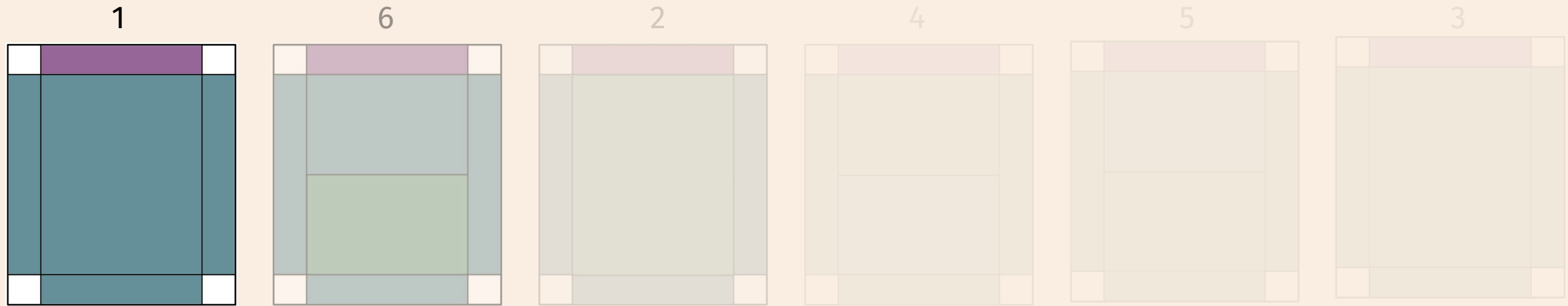
The product



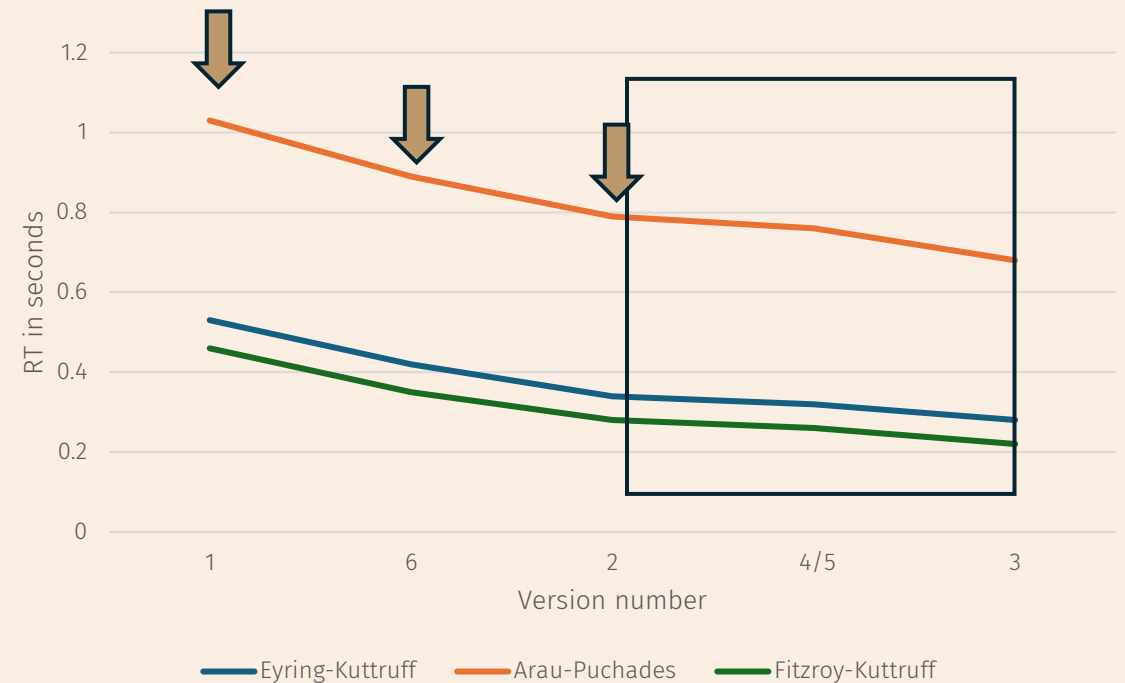
Reflectors

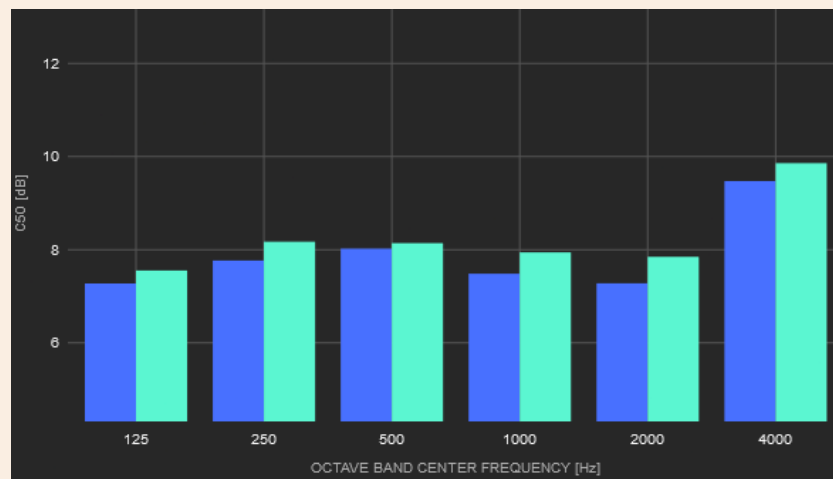
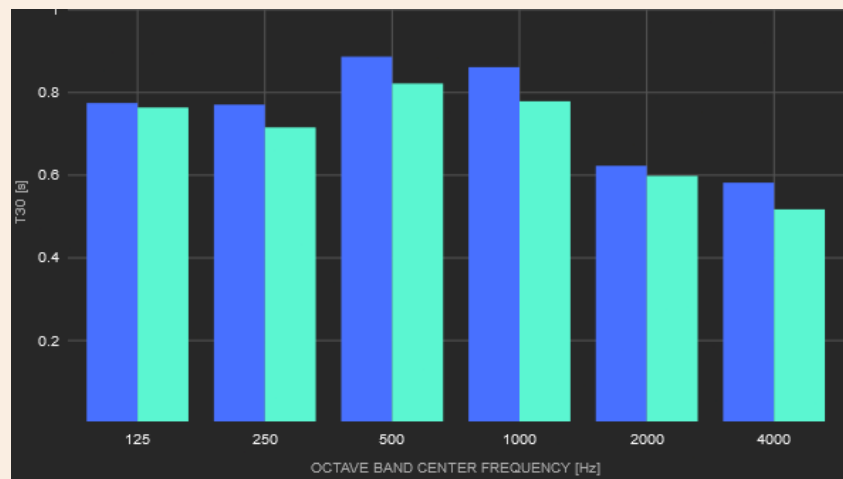
Integrated Design

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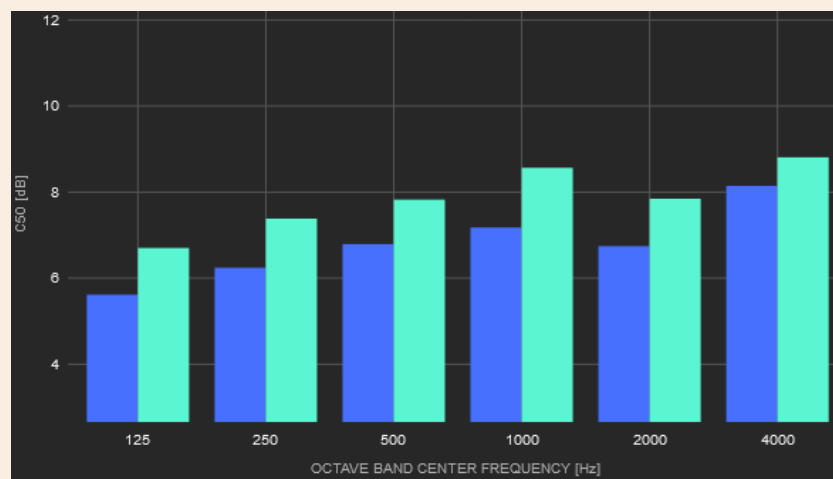
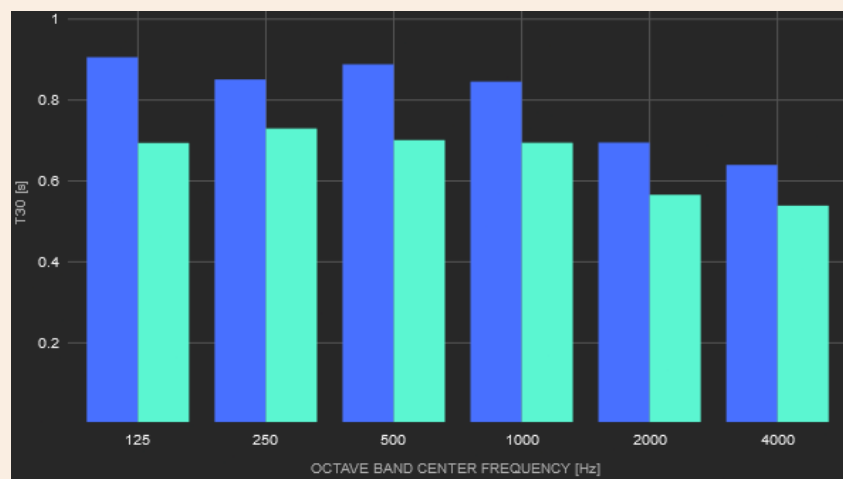
| Version | Surface area of Absorption | Surface Area | Volume of Space | Decrease in RT |
|---------|----------------------------|--------------|-----------------|----------------|
| 1 | 43.7 | 198.9 | 163.9 | - |
| 6 | 56.75 | 211.95 | 163 | 0.11-0.14 |
| 2 | 69.8 | 225 | 162.12 | 0.07-0.1 |
| 4/5 | 74.45 | 229.65 | 161.82 | 0.02-0.03 |
| 3 | 87.5 | 242.7 | 160.79 | 0.04-0.08 |





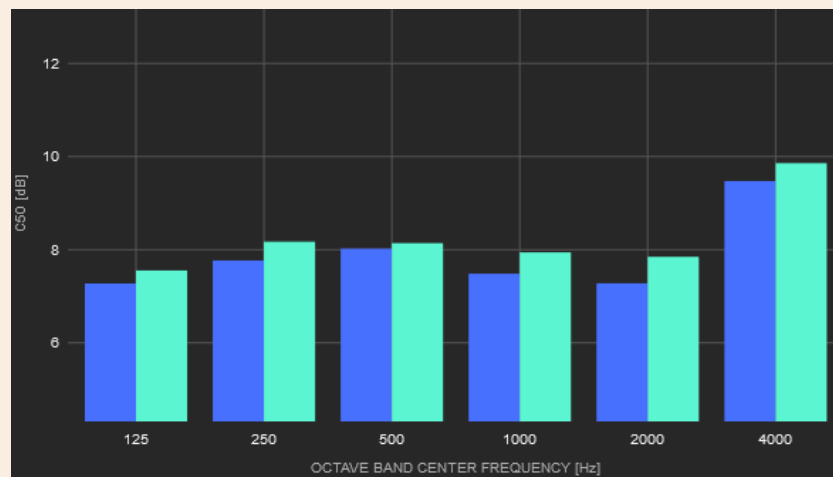
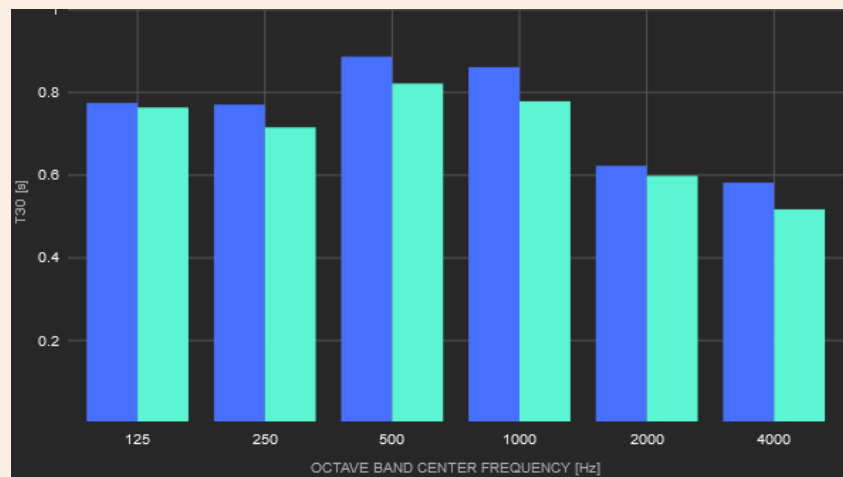
- Target: Independent learning, group work

Flat ceiling
Hip ceiling



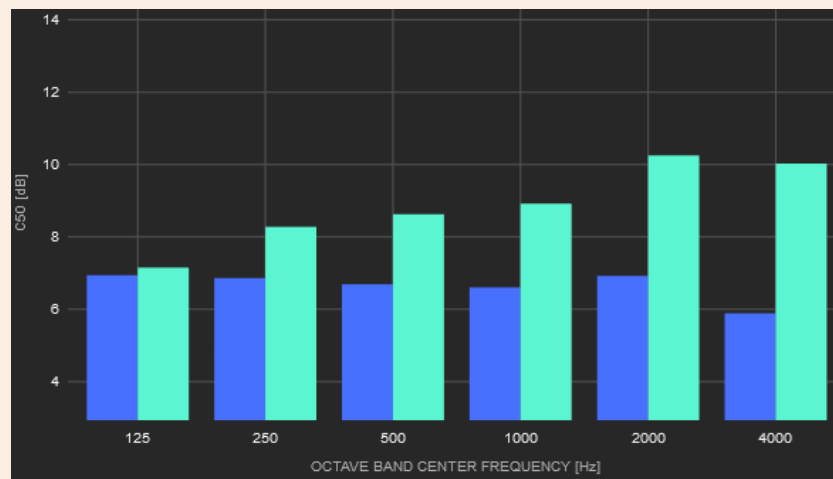
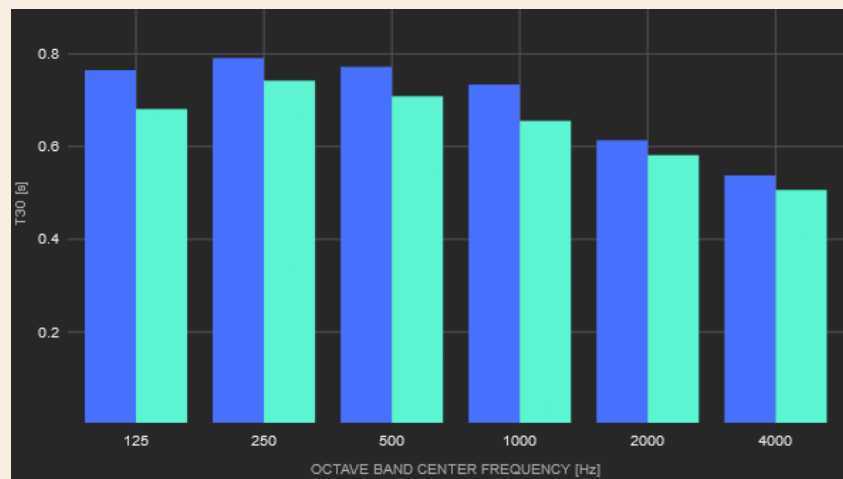
- Target: Teacher centered
- Reduction in RT of 0.11-0.14s

■ Flat ceiling
■ Hip ceiling



- Target: Independent learning, group work

■ Flat ceiling
■ Hip ceiling



- Target: Independent learning, group work
- Reduction in RT of 0.18-0.24s

■ Flat ceiling
■ Hip ceiling

Option 1

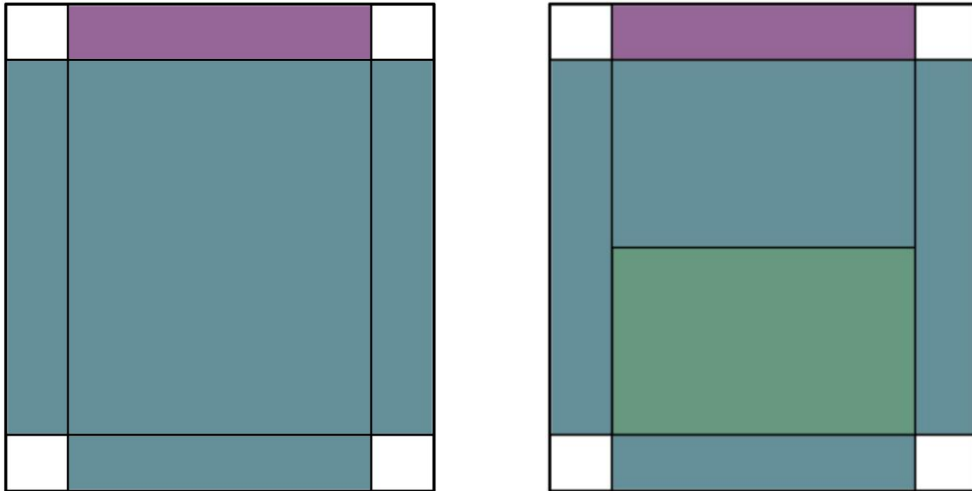
General

Version 1 – tasks with lesser singular focus needed

Version 2 – tasks with higher singular focus

Effective reduction in RT of 0.11-0.14s

Effective increase in C35 by 2-4 dB at pos. 15



Option 2

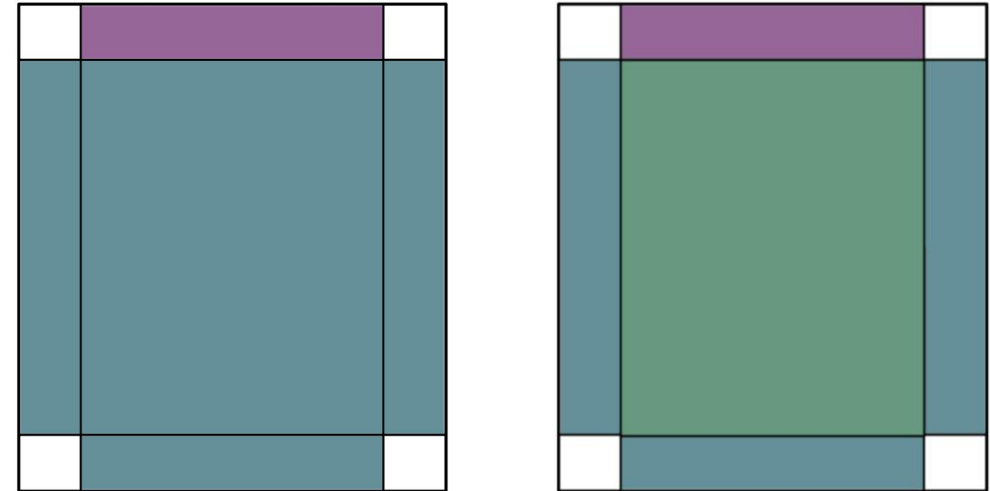
Classes with additional learning needs

Version 1 – tasks with lesser singular focus needed

Version 2 – tasks with higher singular focus

Effective reduction in RT of 0.18-0.24s

Effective increase in C35 by 2-4 dB at pos. 15



Limitations

Ceiling

- More elaborate researching needed into the impact of ceiling profiles – use optimisation software/tools
- Analyse based on C35 from the get-go

Integrated Design

- Verification of results
- Passive, dynamic design to achieve results

Future Developments

Ceiling

- More elaborate researching needed into the impact of ceiling profiles – use optimisation software/tools
- Analyse based on C35 from the get-go – use optimisation software/tools

Integrated Design

- Verification of results
 - Live measurements
 - Manual calculation in accordance with NEN-EN 12354-6, Appendix D
 - Check – the limits of geometry subject to wave solvers
- Passive, dynamic design to achieve results
 - Check the integration of technology to improve signal-to-noise ratio (and thus, speech clarity)

“How do the various teaching styles, and the acoustic requirements of a middle school learning environment influence the implementation of acoustic control systems?”



Thank you!

questions?