The Sound of Recycling

Transfoaming glass waste into acoustic panels

P5 Presentation | **Ludwika Buczyńska** | 6068804

Supervised by:

Dr. Faidra Oikonomopoulou Structures and Materials
Prof. Martin Tenpierik Environmental and Climate Design
Dr. Gabriele Mirra Digital Technologies

Delft University of Technology

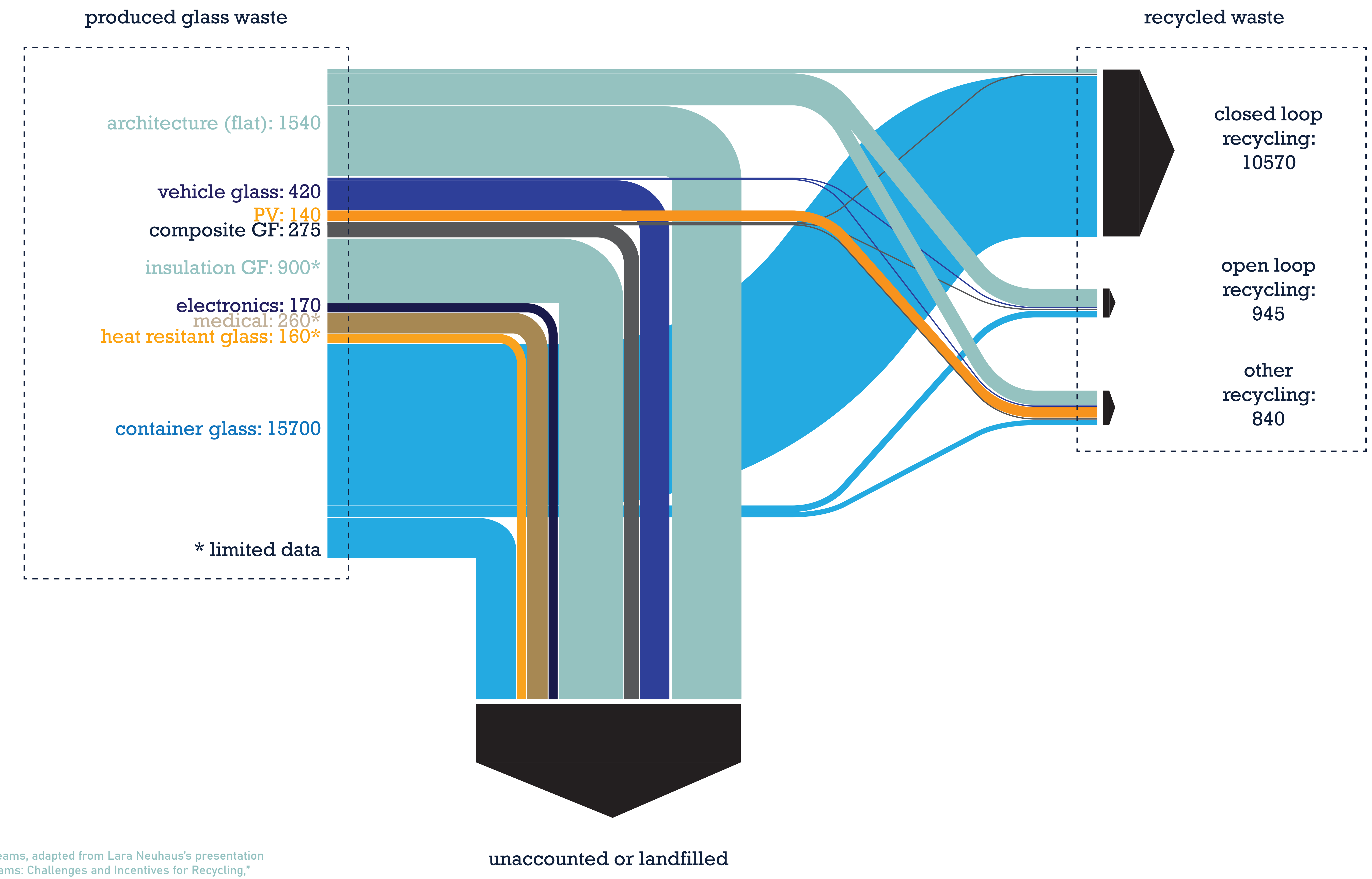
Presented on 23 June 2025 | MSc Architecture, Urbanism & Building Sciences | Building Technology Graduation Studio


BACHER
TUSSOCK JUMPER

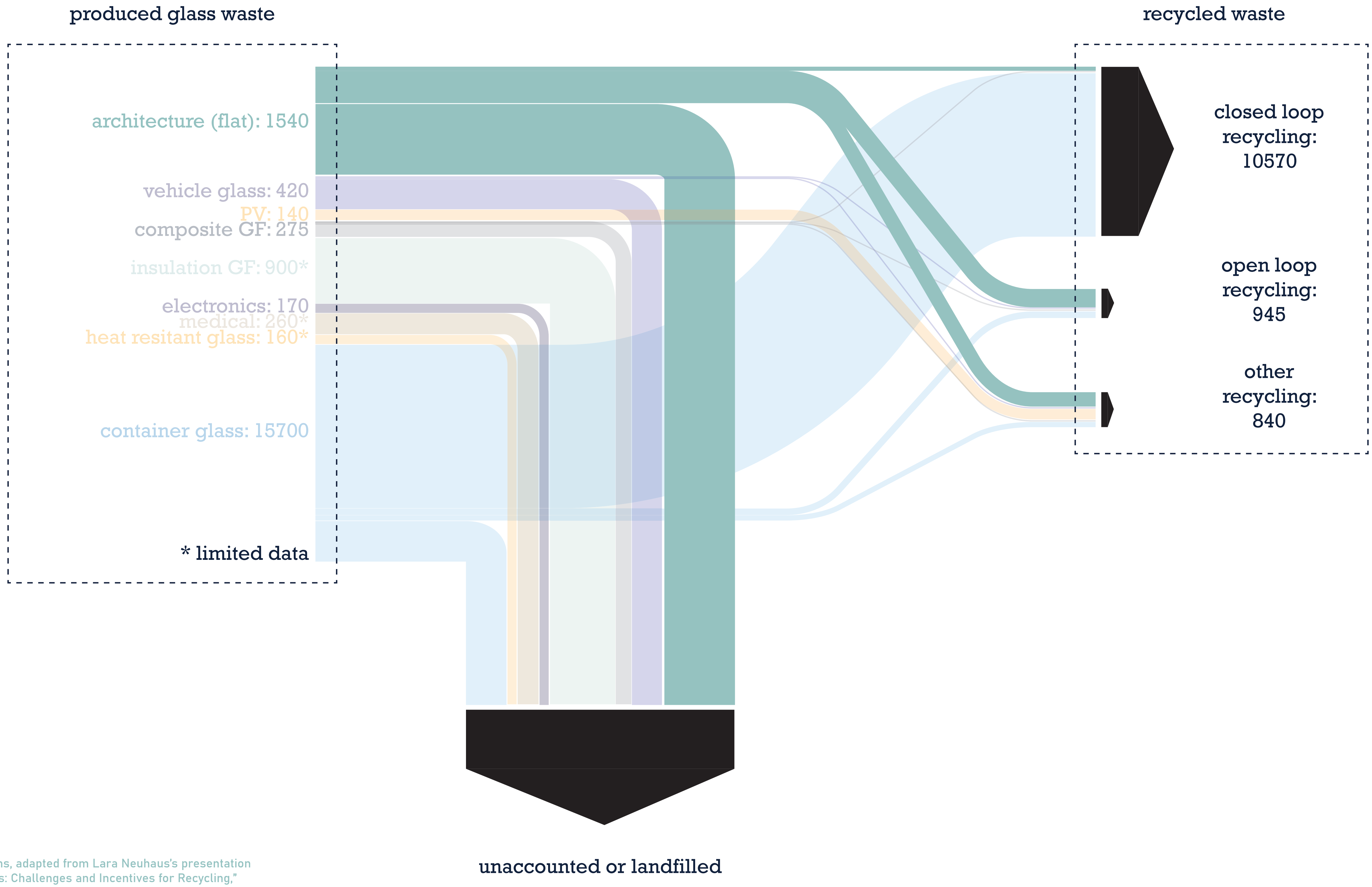

eDrive

"Apart from **container glass** being successfully recycled in a **closed-loop** in Europe, the rest of the commercial glass waste is, in its majority, **downcycled** or **landfilled**."

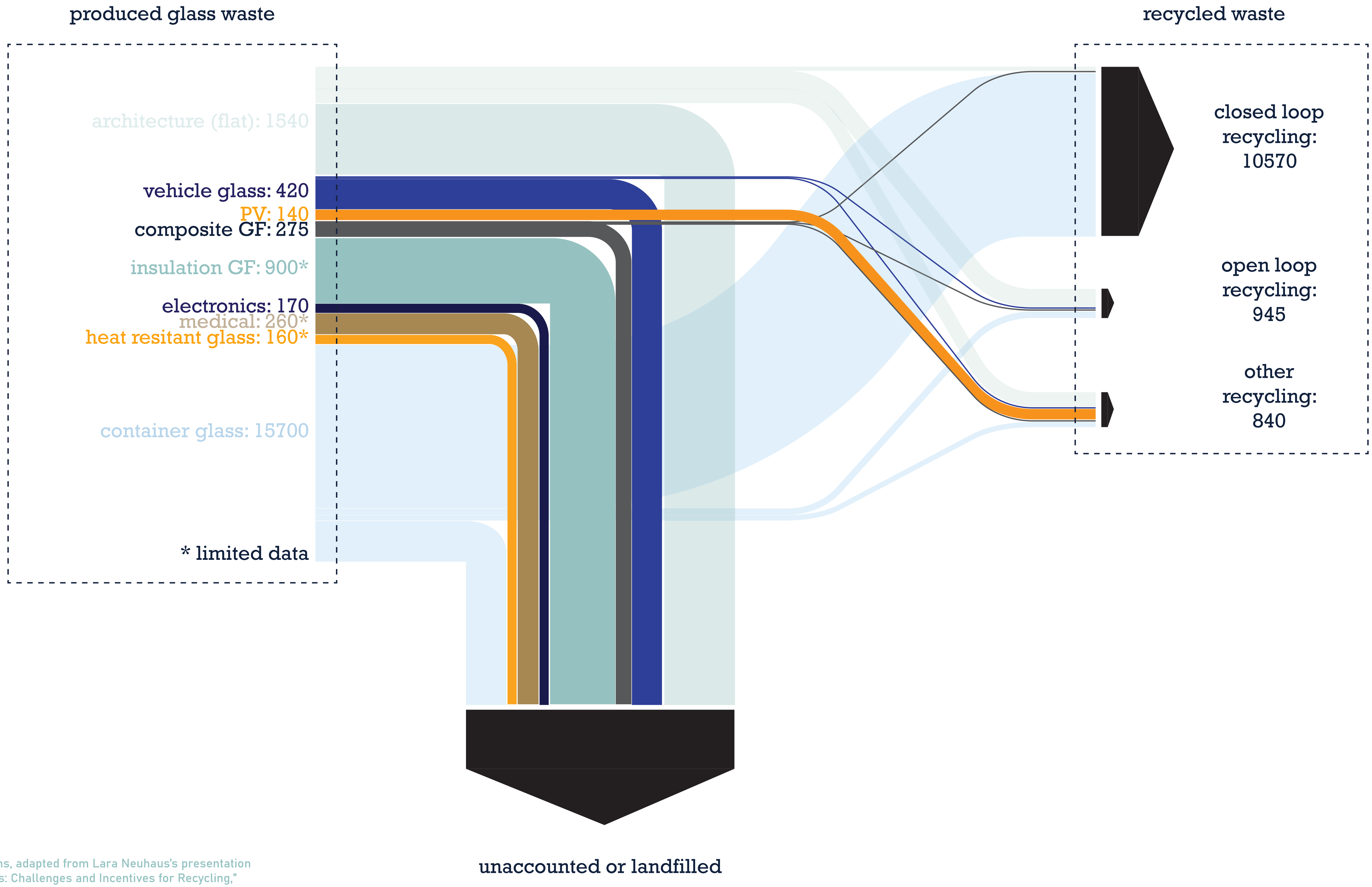
Bristogianni & Oikonomopoulou, 2023



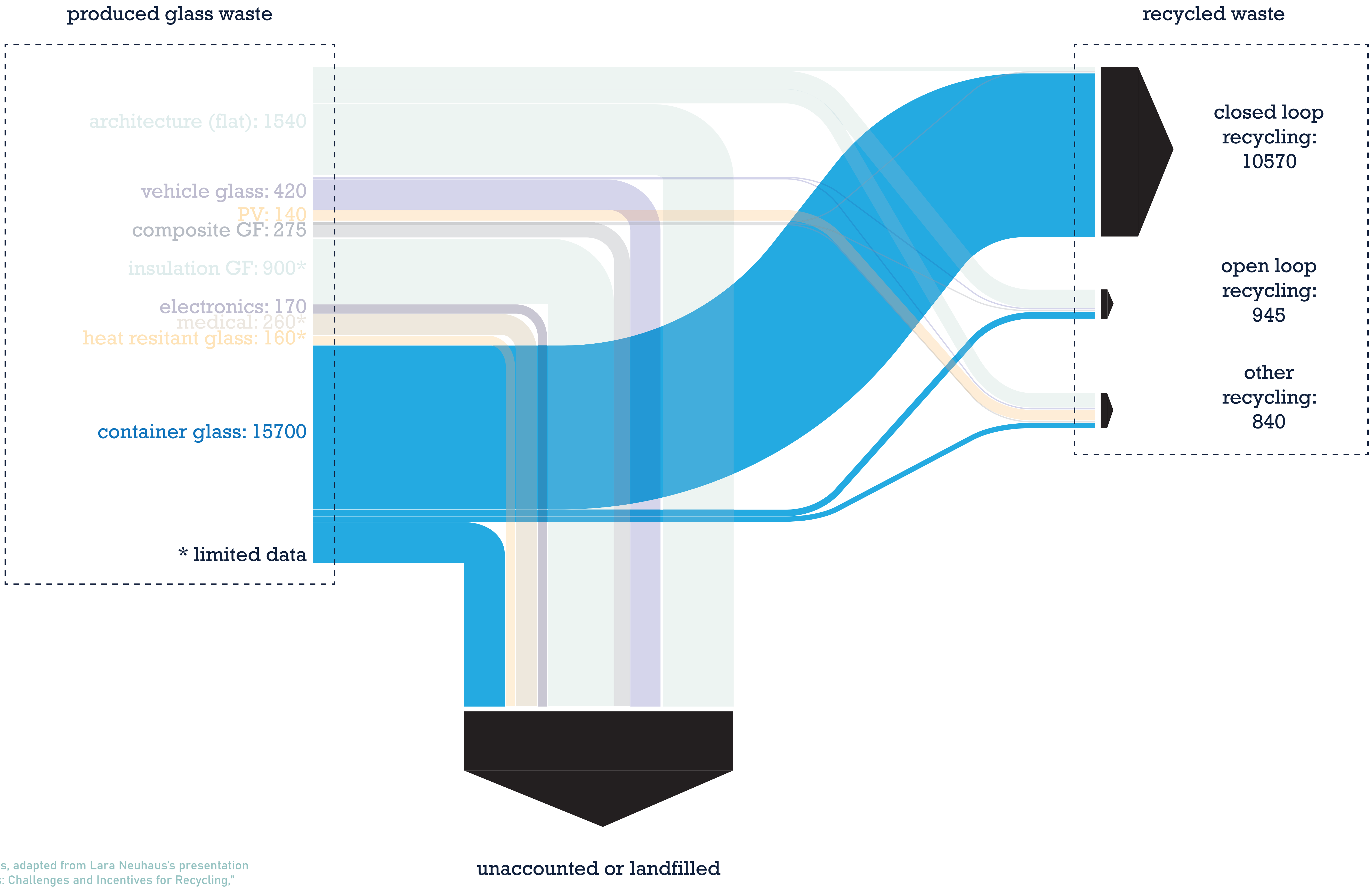
Scheme of glass waste streams, adapted from Lara Neuhaus's presentation "Mapping Glass Waste Streams: Challenges and Incentives for Recycling," presented at the Glass Forum 2025, TU Delft, on March 19.



Scheme of glass waste streams, adapted from Lara Neuhaus's presentation "Mapping Glass Waste Streams: Challenges and Incentives for Recycling," presented at the Glass Forum 2025, TU Delft, on March 19.



Scheme of glass waste streams, adapted from Lara Neuhaus's presentation "Mapping Glass Waste Streams: Challenges and Incentives for Recycling," presented at the Glass Forum 2025, TU Delft, on March 19.



Scheme of glass waste streams, adapted from Lara Neuhaus's presentation "Mapping Glass Waste Streams: Challenges and Incentives for Recycling," presented at the Glass Forum 2025, TU Delft, on March 19.

"Every tonne of cullet utilised saves

1.2 tonnes of

raw materials

300kWh of

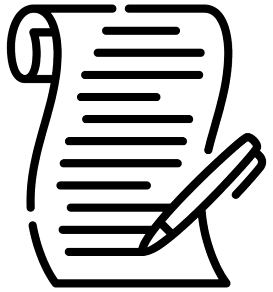
energy

300kg of

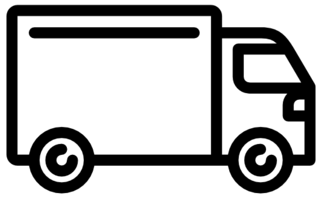
CO_2 emissions"

DeBrincat and Babic, ARUP, 2018

supply-chain challenges



lack of legislations



complicated logistics

technical challenges

pyrex.co.uk

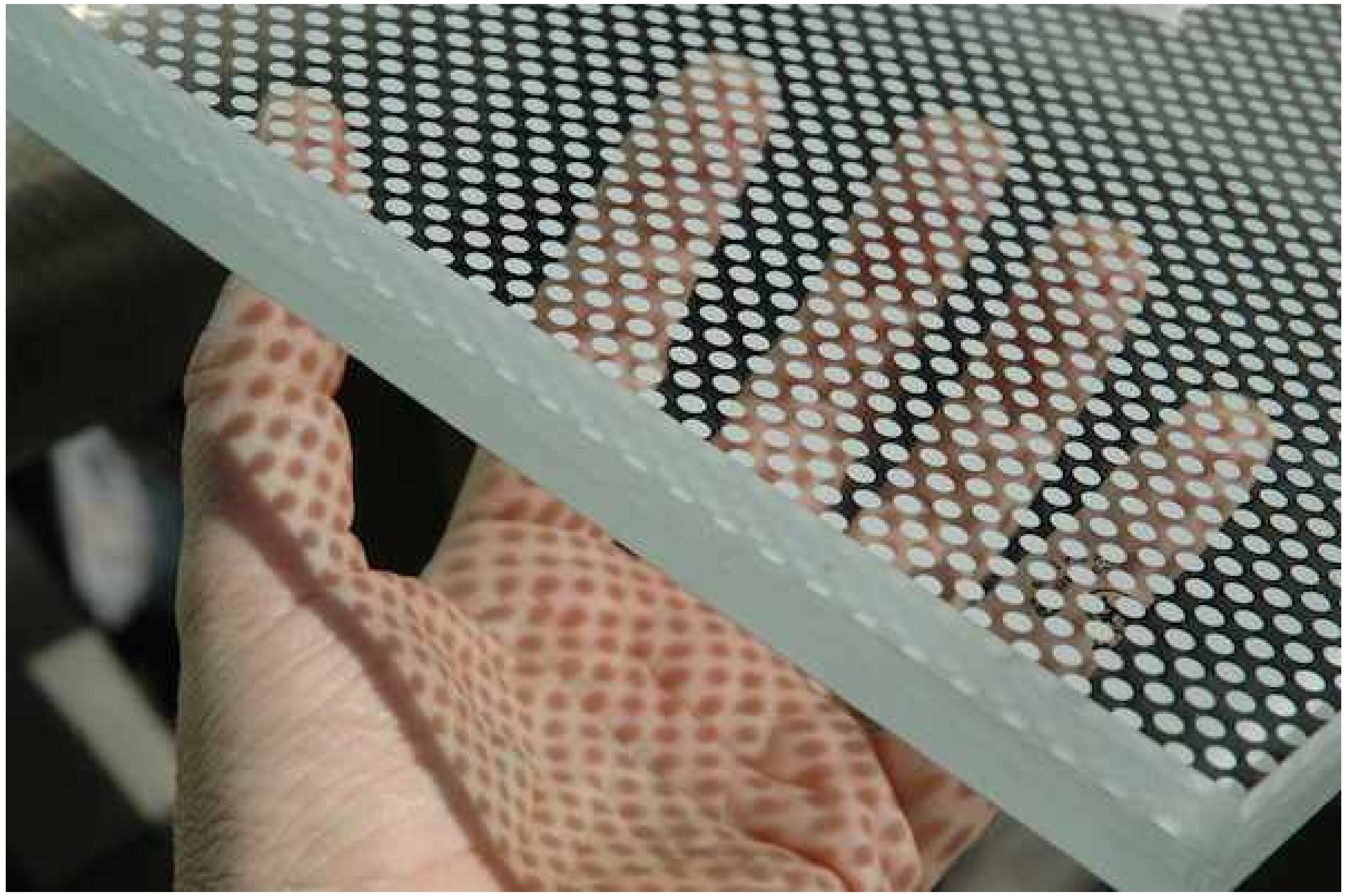

glassmagazine.com

technical challenges

lamination

made2measure.co.uk

frittings/coatings



ceramics.org

?

?

waste

↓

raw material

cast glass

Glass samples of RE3 project, made by Faidra Oikonomopoulou et al., 2018.

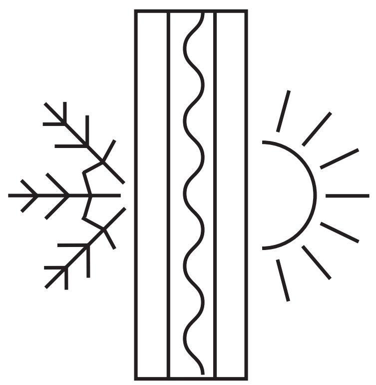
foam glass

"In the production of foam glass, up to 70% of the needed raw material can be substituted by waste glass"

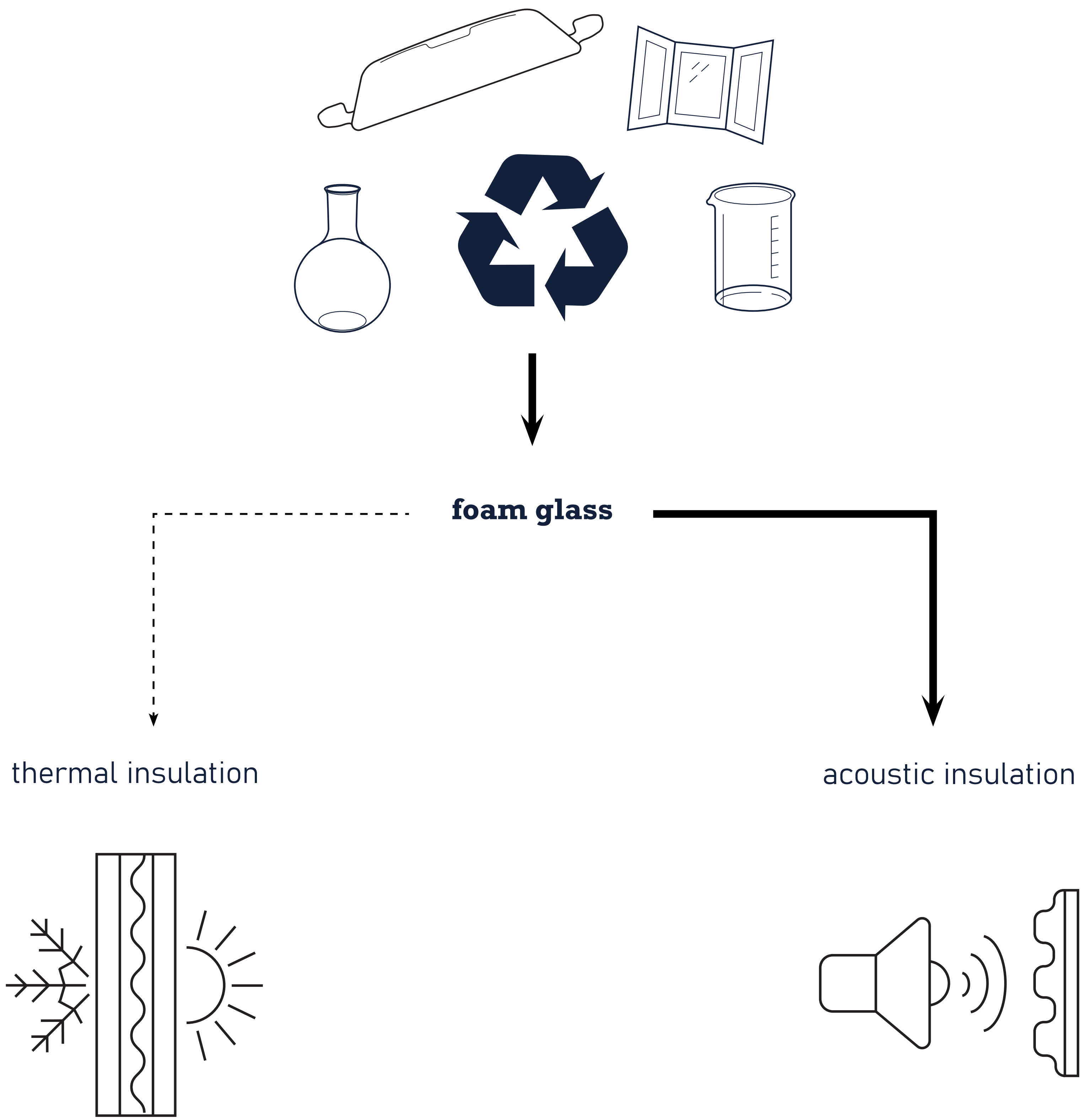
Hesky et al., 2015

foam glass

thermal insulation




foam glass
thermal insulation
acoustic insulation

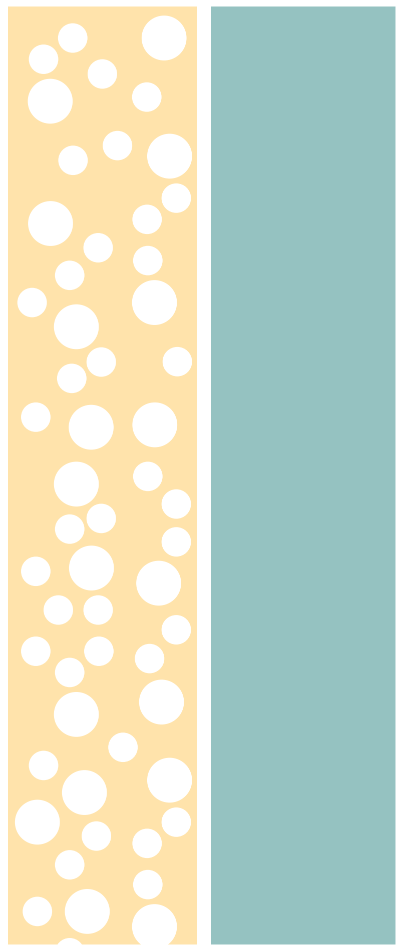

foam glass
thermal insulation
acoustic insulation

"Sound absorption materials structure is generally based on porous **synthetic media**; they have **expensive production processes**, important **energy consumptions**, and **high environmental impact**."

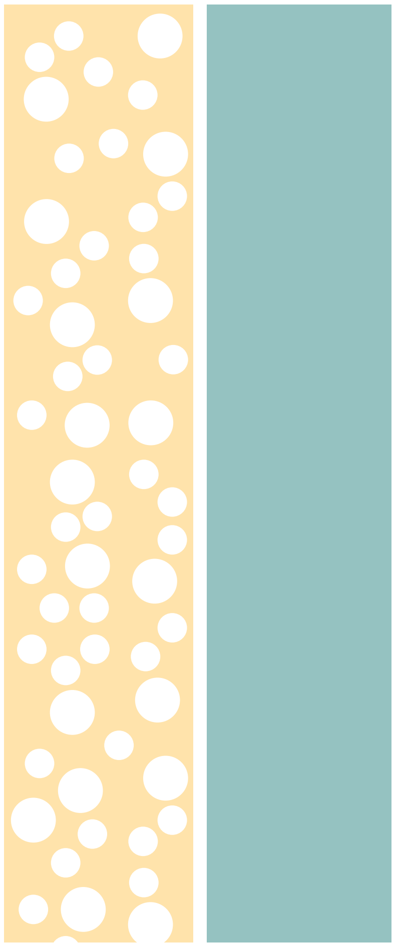
Buratti et al., 2016

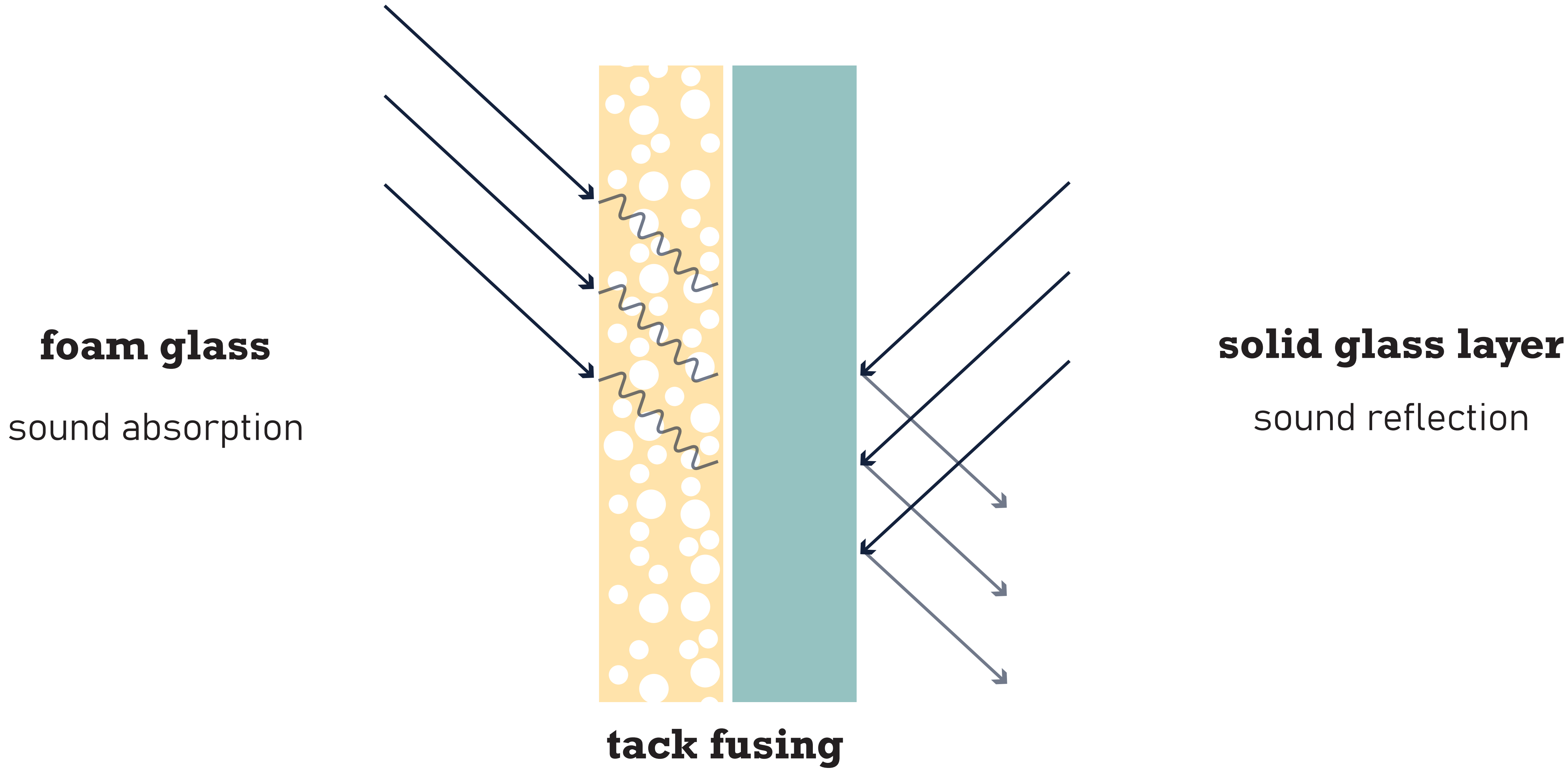
foam glass

foam glass



solid glass layer


foam glass
solid glass layer
tack fusing

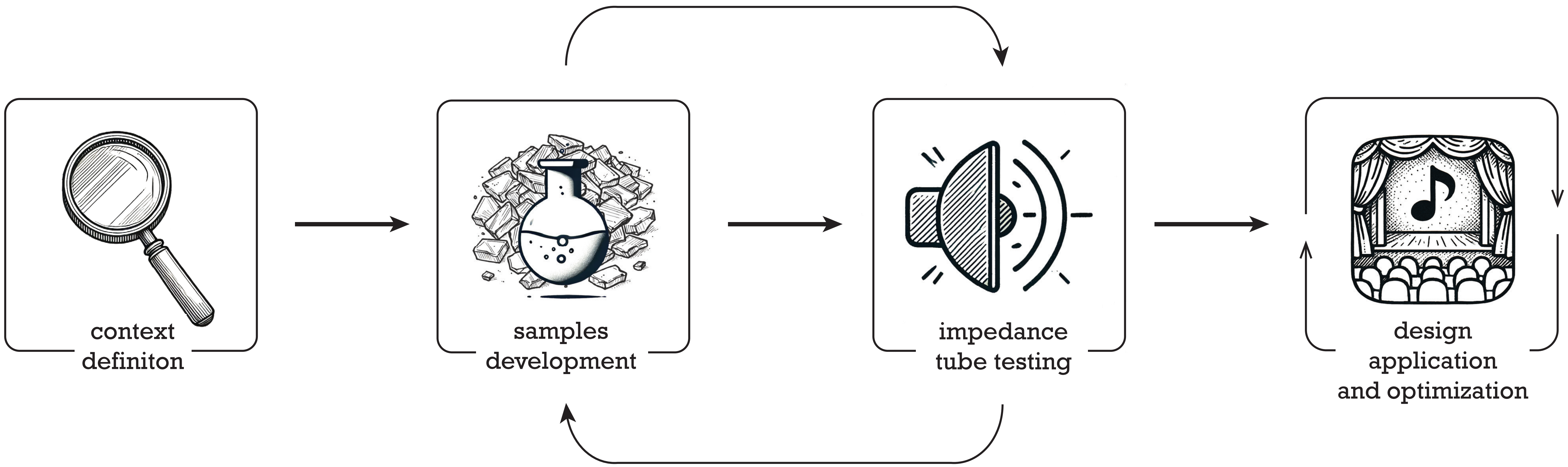

foam glass
sound absorption
solid glass layer
sound reflection
tack fusing

What are the potential and limitations of developing a porous material from glass waste to produce acoustic panels for architectural space?

context definition

experimental research

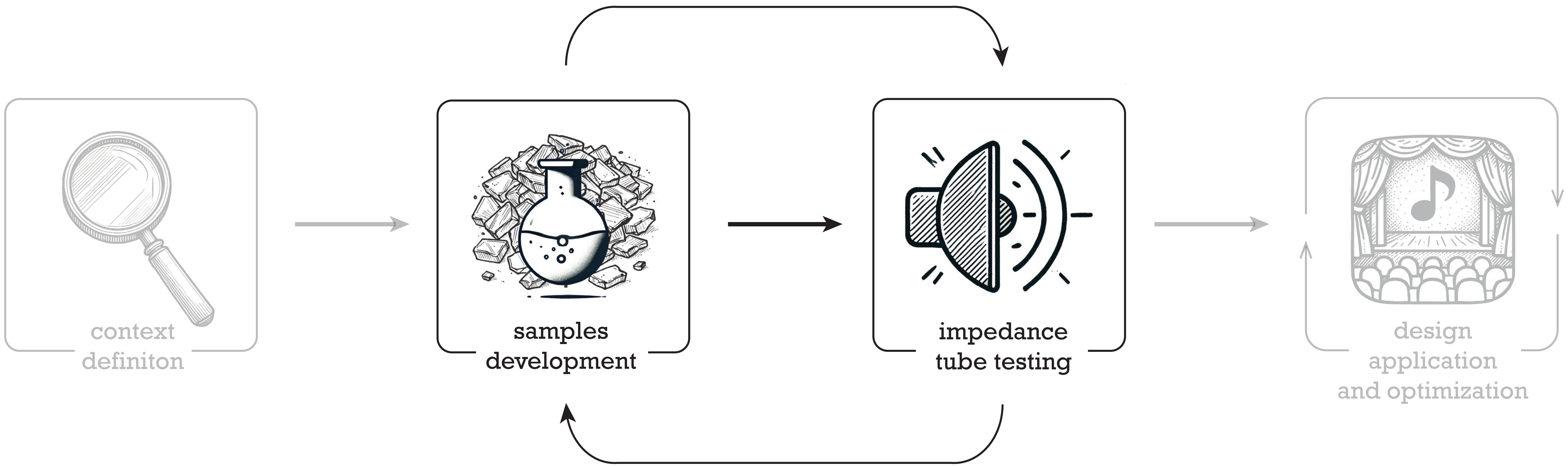
design application



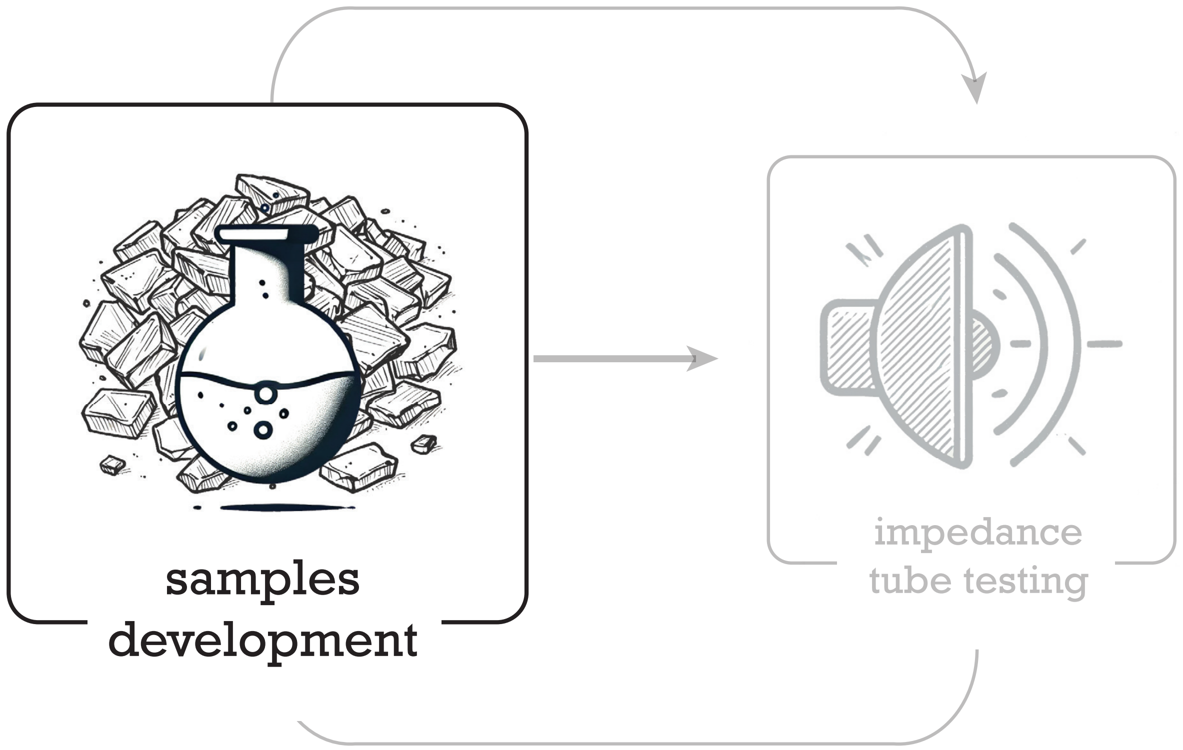
context definition

experimental research

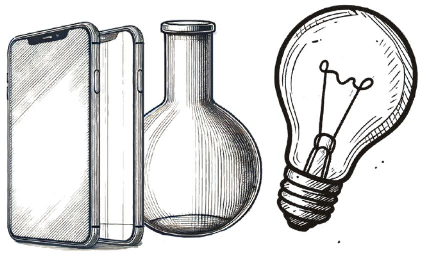
design application



manufacturing



manufacturing

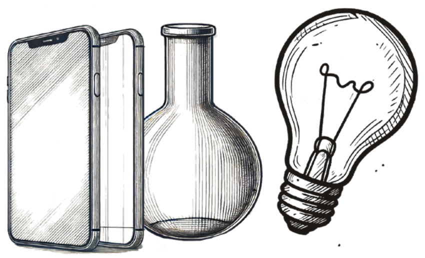


glass waste

+

foaming agent

manufacturing

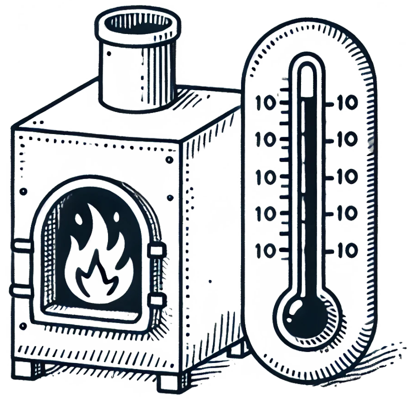


glass waste

+

foaming agent

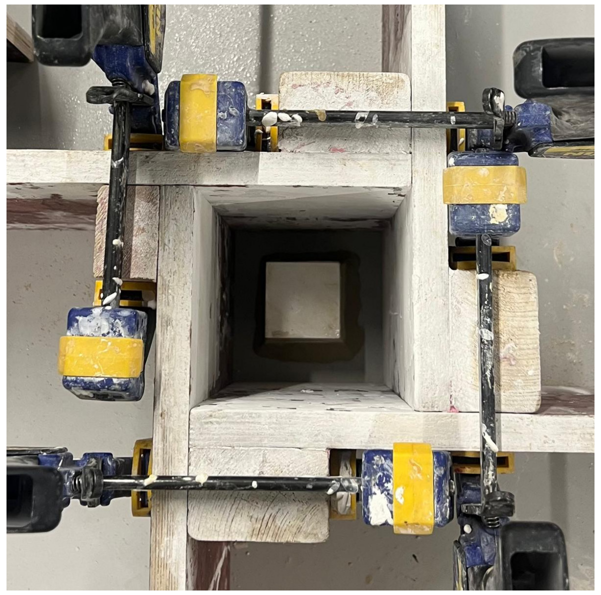
→

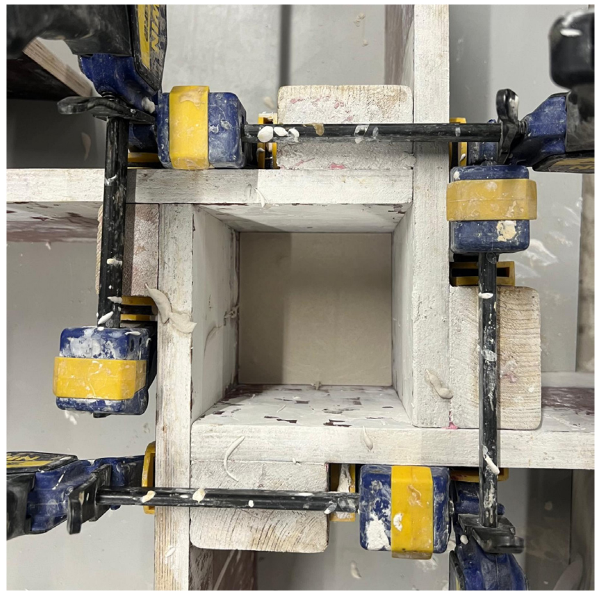


firing

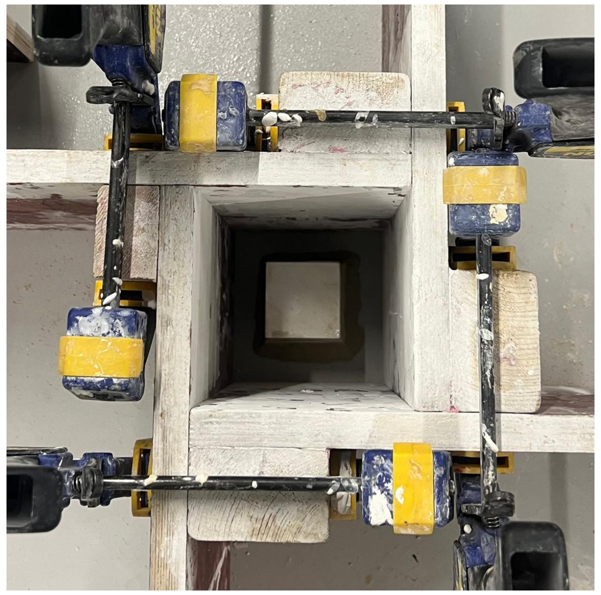
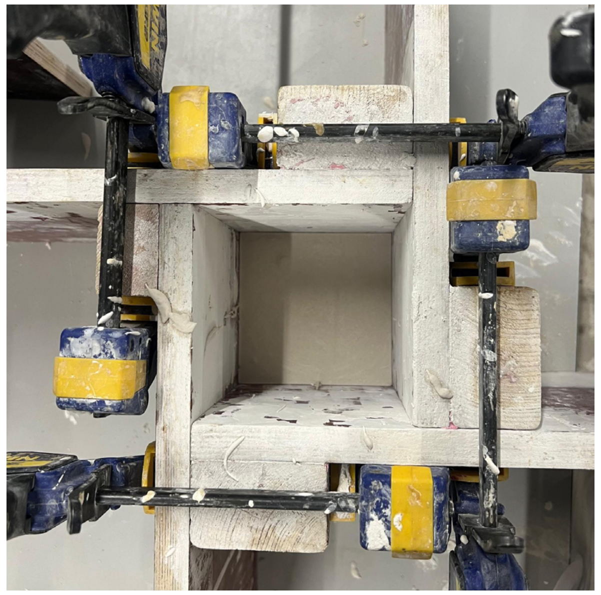
manufacturing

mould making

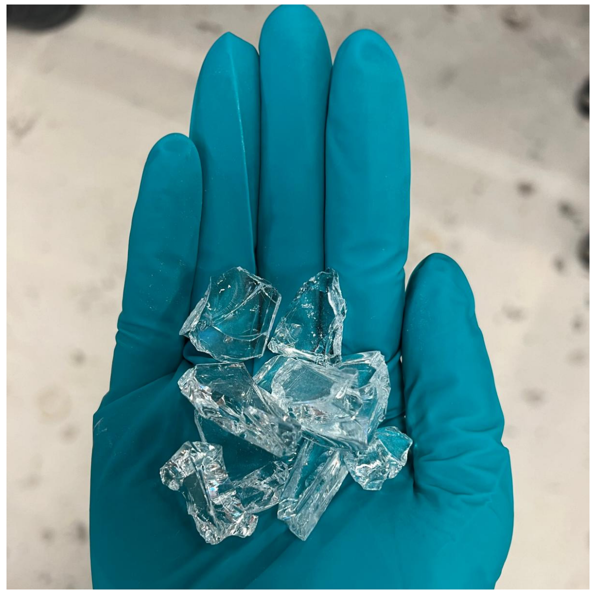




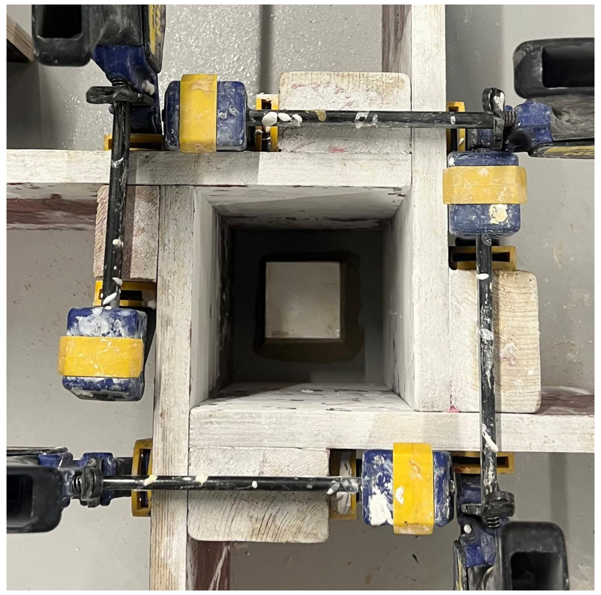
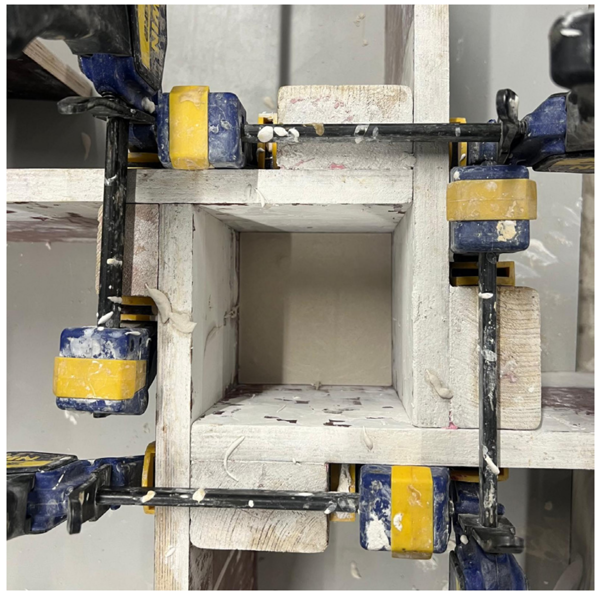
mould making

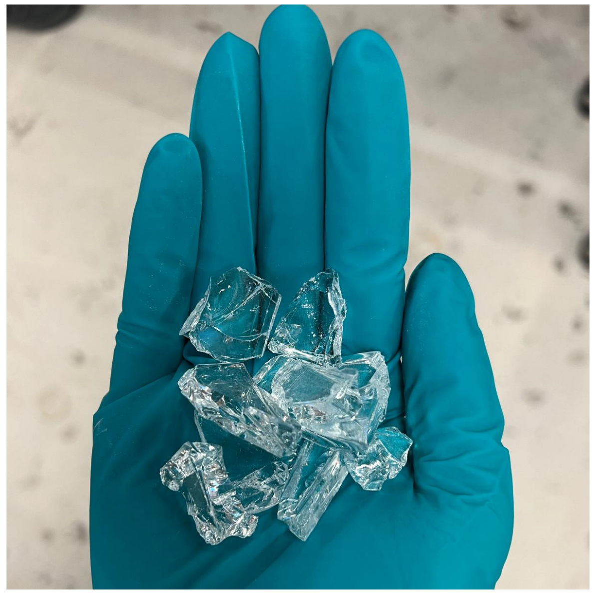

cullet preparation

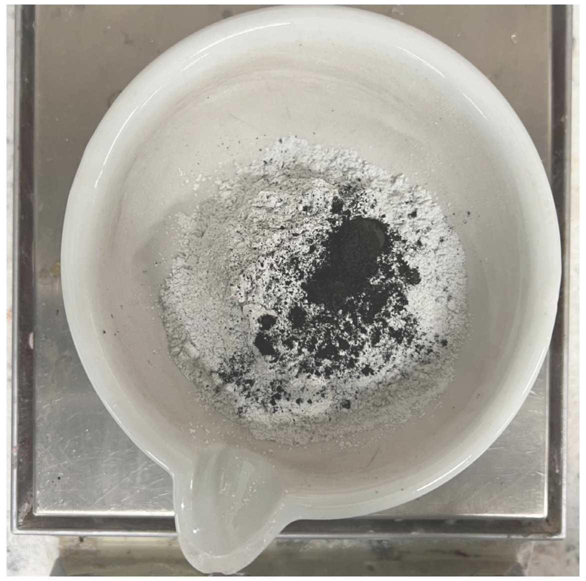
mould making

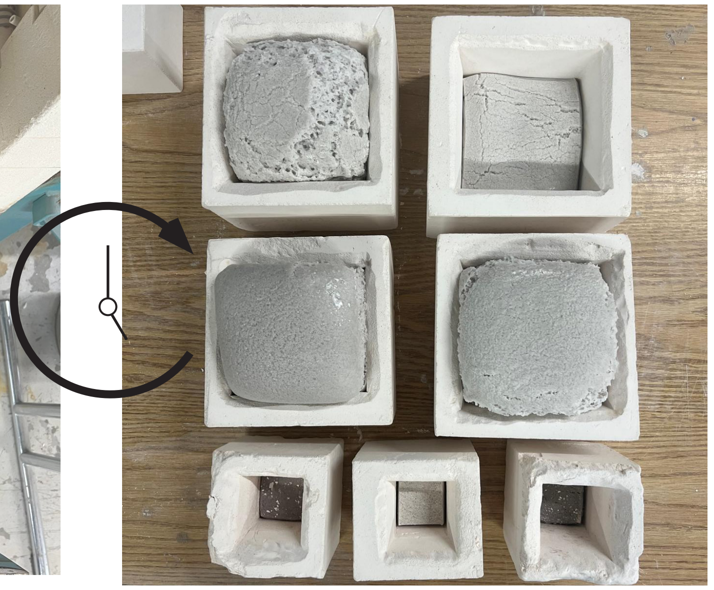




cullet preparation

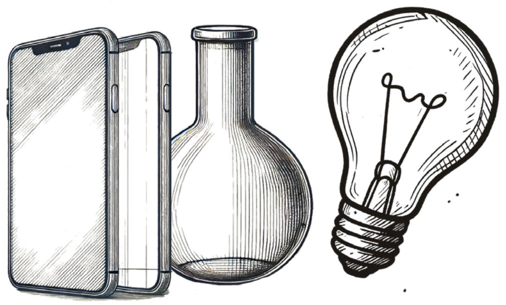
mixing, firing, sample extraction






What affects foaming?

What affects foaming?

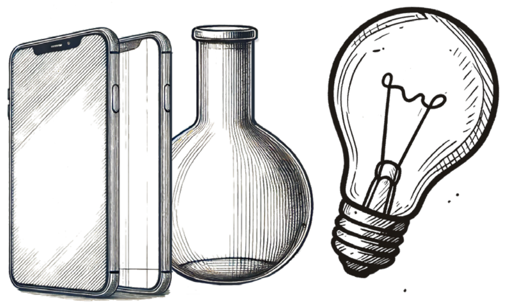


glass waste type

+

foaming agent

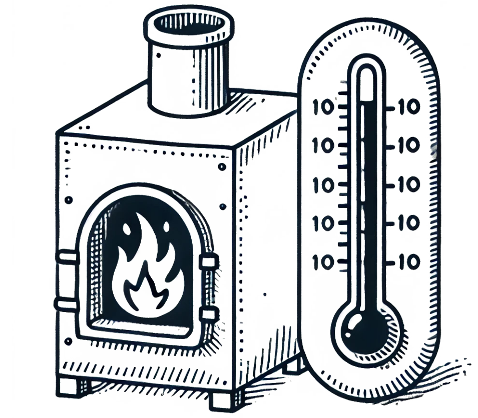
What affects foaming?



glass waste type

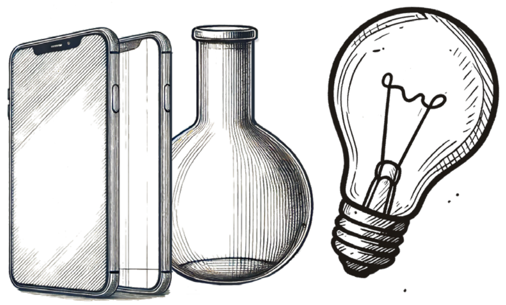
+

foaming agent



firing schedule

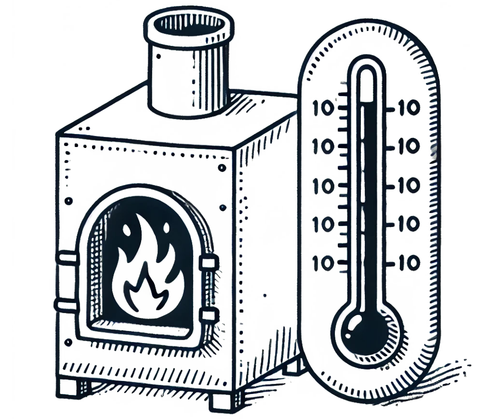
What affects foaming?



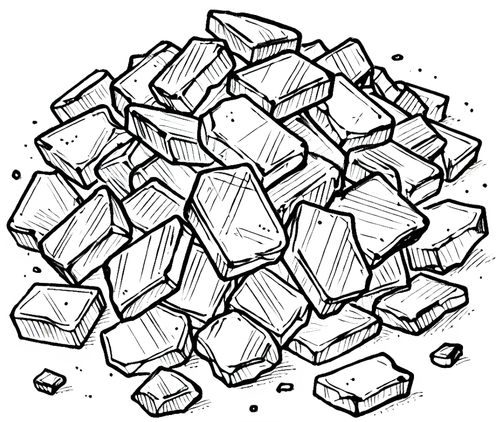
glass waste type

+

foaming agent

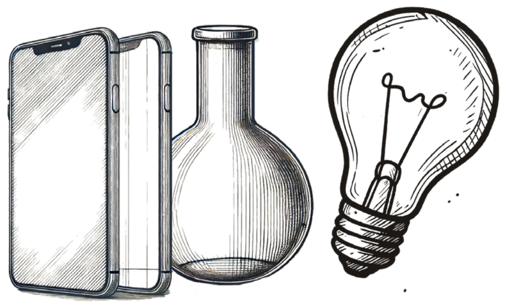


firing schedule



glass cullet size

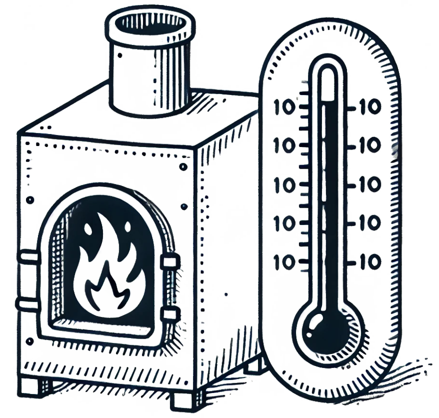
What affects foaming?



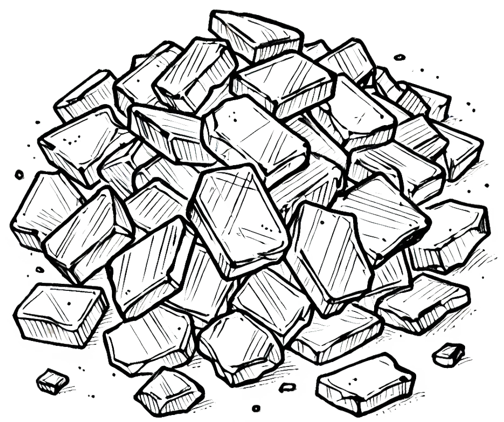
glass waste type

+

foaming agent



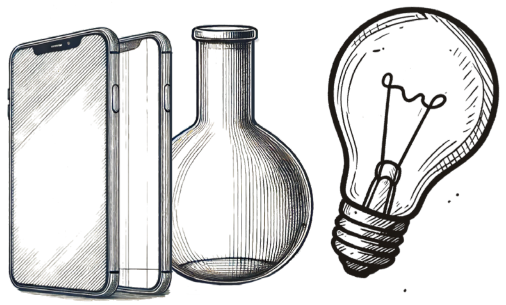
firing schedule



glass cullet size

foaming agent
particle size

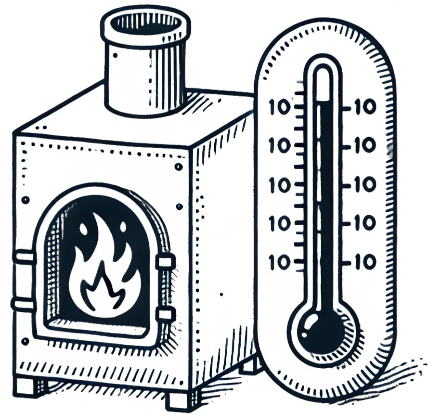
What affects foaming?



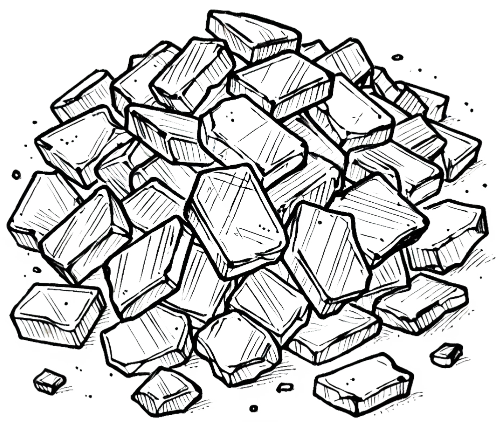
glass waste type

+

foaming agent

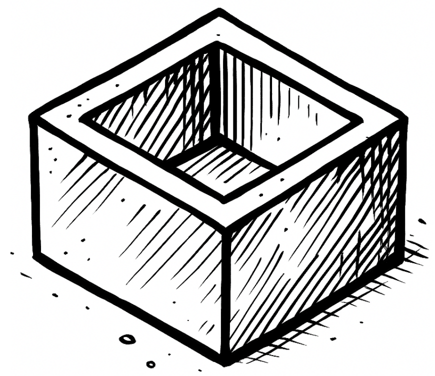


firing schedule



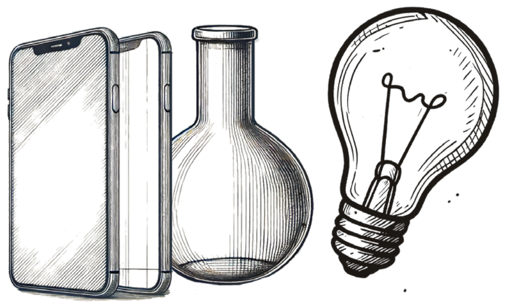
glass cullet size

foaming agent
particle size



mould size/
geometry

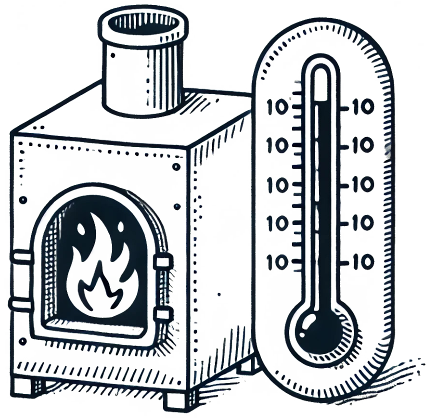
What affects foaming?



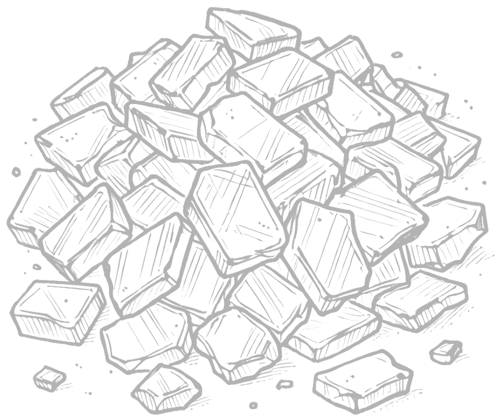
glass waste type

+

foaming agent

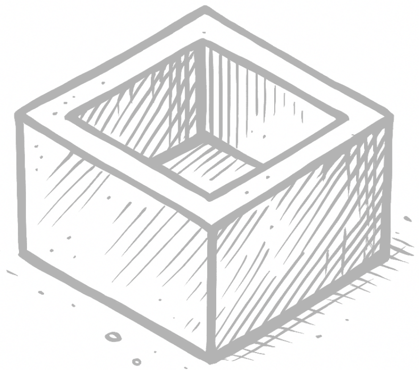


firing schedule



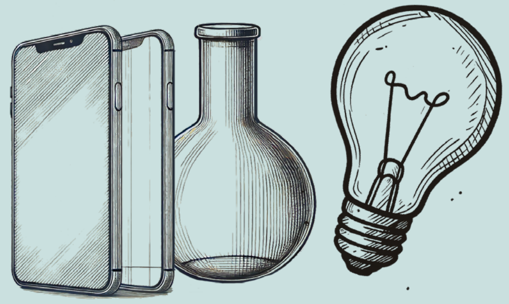
glass cullet size

foaming agent
particle size



mould size/
geometry

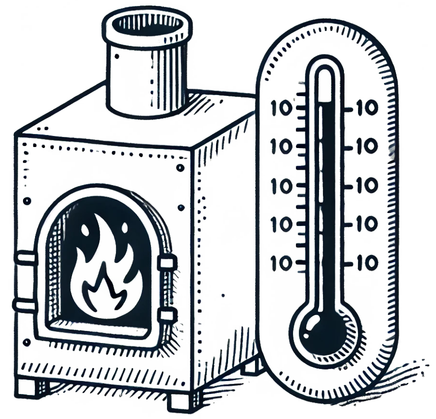
What affects foaming?



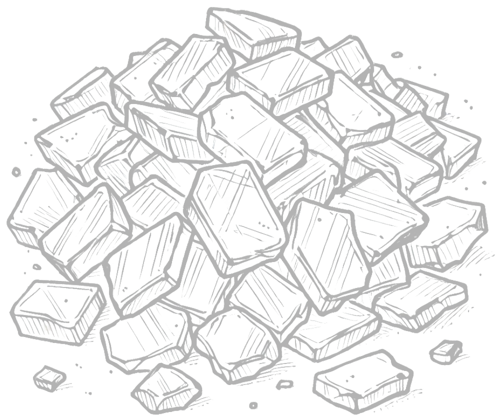
glass waste type

+

foaming agent

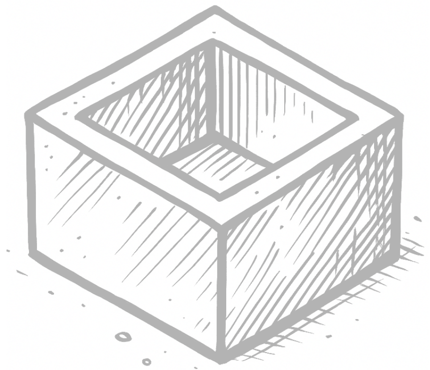


firing schedule



glass cullet size

foaming agent particle size



mould size/ geometry

SODA LIME

tested parameters

glass (waste) type

SODA LIME

low-iron soda lime

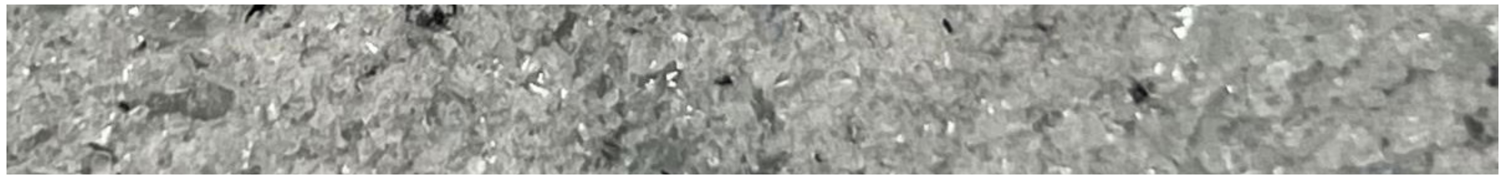
tested parameters

glass (waste) type

SODA LIME

low-iron soda lime

automotive



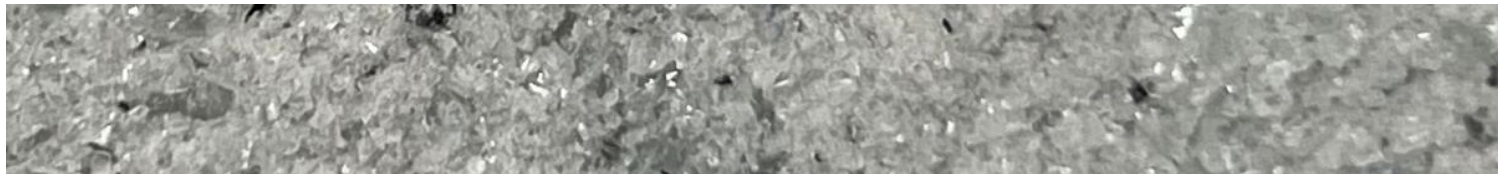
tested parameters

glass (waste) type

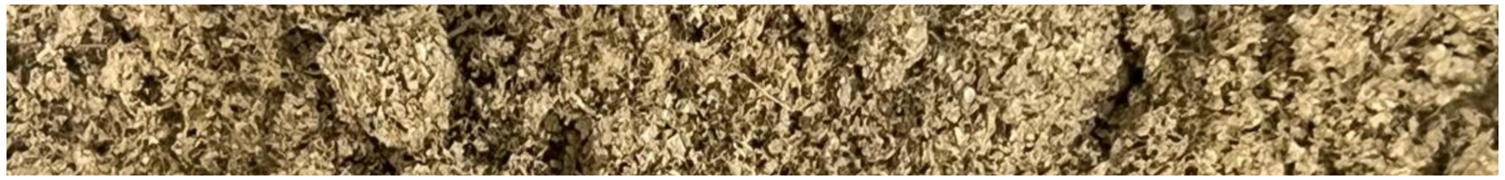
SODA LIME

low-iron soda lime

automotive



Cyclon mix



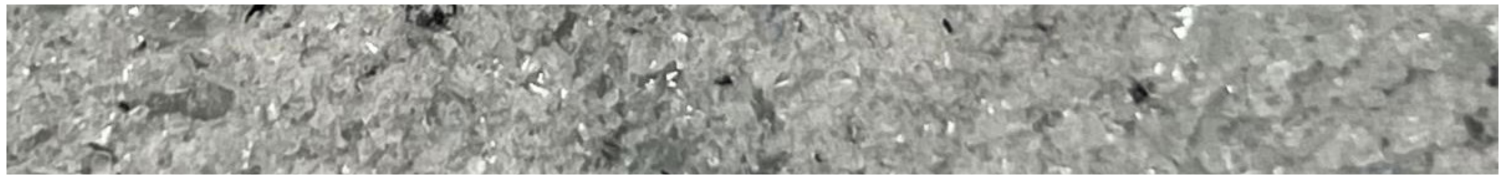
tested parameters

glass (waste) type

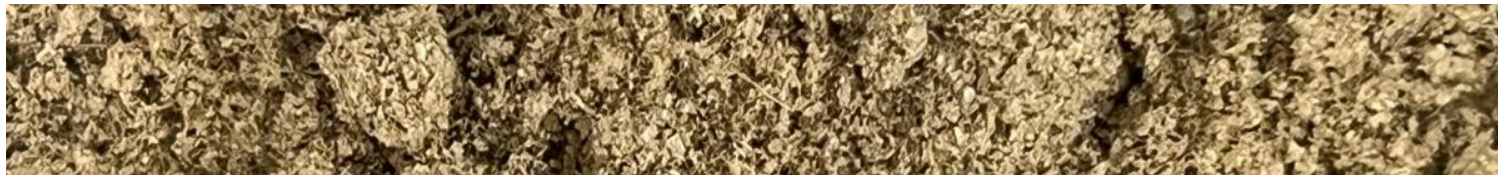
SODA LIME

low-iron soda lime

automotive



Cyclon mix



mix

light bulbs

mixed cullet

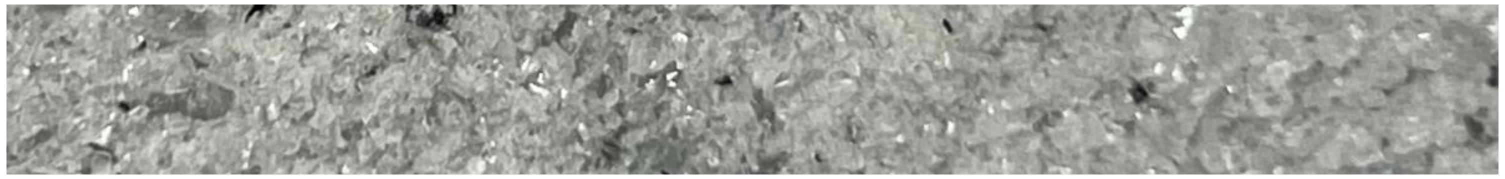
tested parameters

glass (waste) type

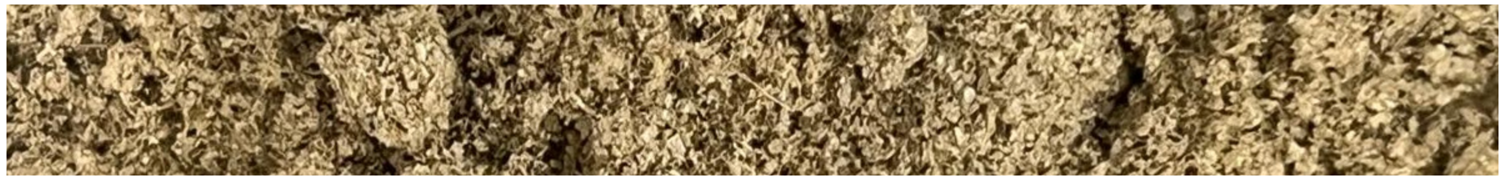
SODA LIME

low-iron soda lime

automotive



Cyclon mix



mix

light bulbs

mixed cullet

ALUMINOSILICATE

mobile phone screens

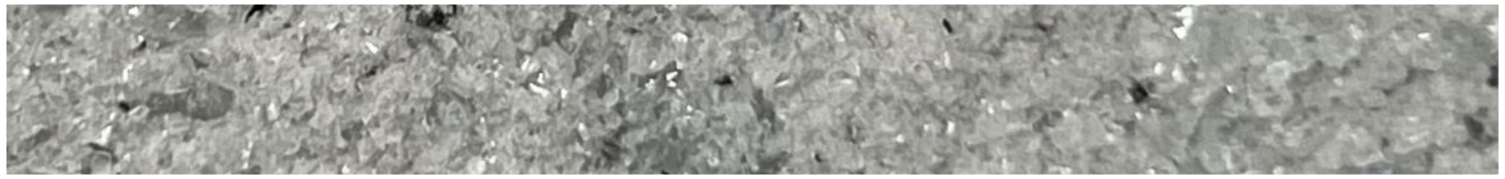
tested parameters

glass (waste) type

SODA LIME

low-iron soda lime

automotive



Cyclon mix

mix

light bulbs

mixed cullet

ALUMINOSILICATE

mobile phone
screens

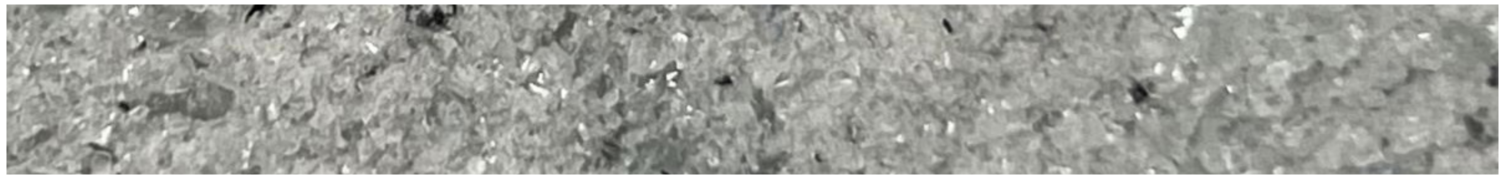
tested parameters

glass (waste) type

SODA LIME

low-iron soda lime

automotive



Cyclon mix

mix

light bulbs

mixed cullet

ALUMINOSILICATE

mobile phone
screens

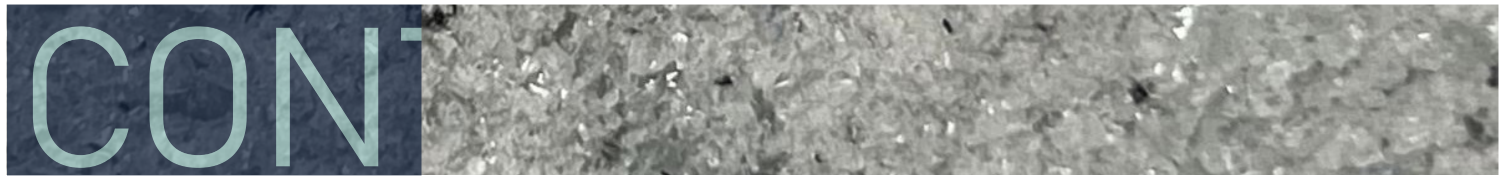
tested parameters

glass (waste) type

SODA LIME

low-iron soda lime

automotive



Cyclon mix

mix

light bulbs

mixed cullet

ALUMINOSILICATE

mobile phone screens

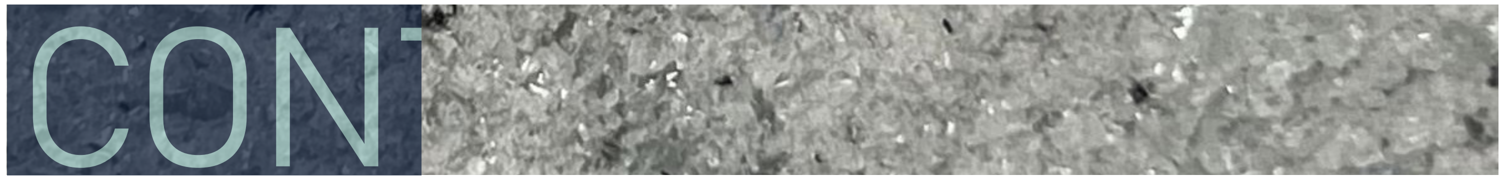
tested parameters

glass (waste) type

SODA LIME

low-iron soda lime

automotive



Cyclon mix

mix

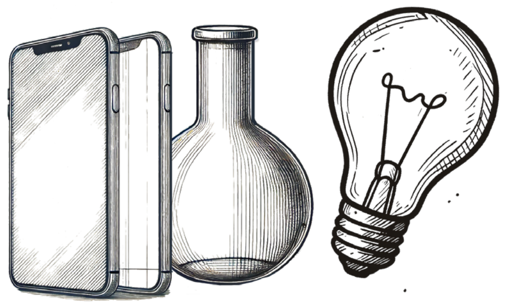
light bulbs

mixed cullet

ALUMINOSILICATE

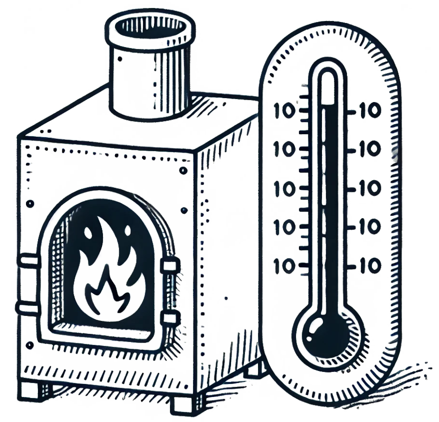
mobile phone screens

What affects foaming?

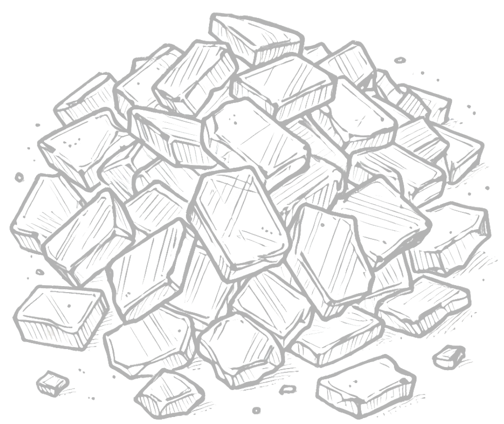


glass waste type

foaming agent

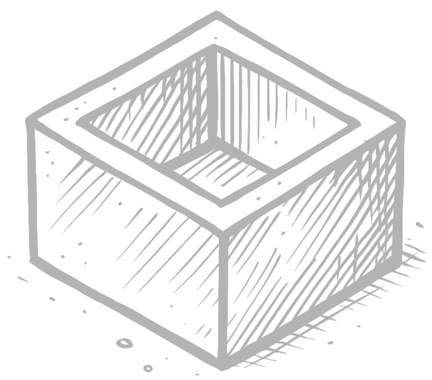


firing schedule



glass cullet size

foaming agent
particle size

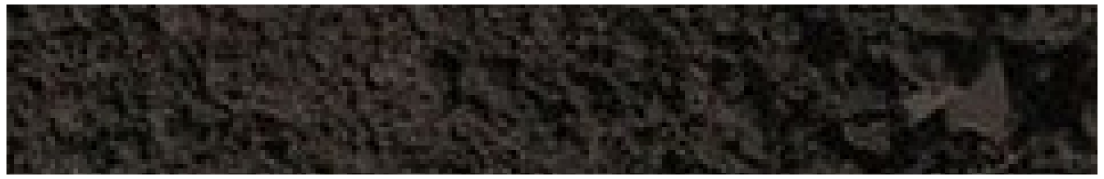
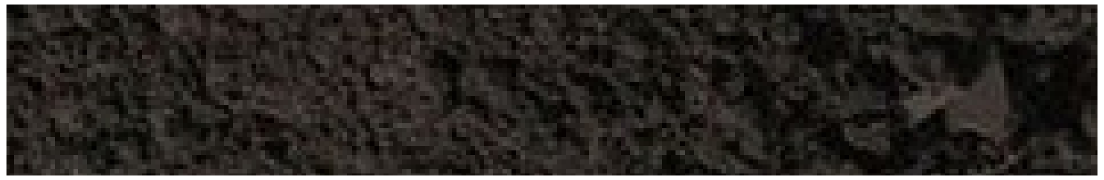


mould size/
geometry

tested parameters

foaming agent

INORGANIC

calcium carbonate	$CaCO_3$		1 - 15 wt %
manganese dioxide	MnO_2		5, 10 wt %
carbon black	C		1 - 5 wt %
dicalcium phosphate	$CaHPO_4$		0.3 - 1.6 wt %

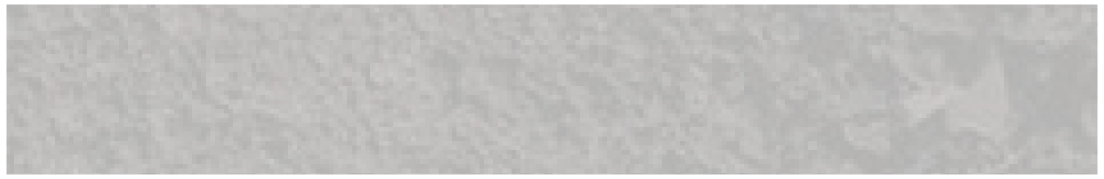
ORGANIC

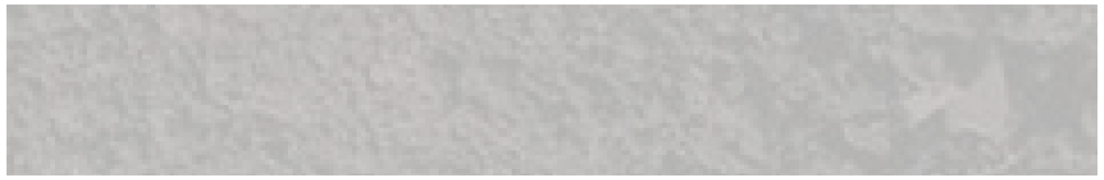
tested parameters

foaming agent

INORGANIC

calcium carbonate $CaCO_3$  1 - 15 wt %

manganese dioxide MnO_2  5, 10 wt %

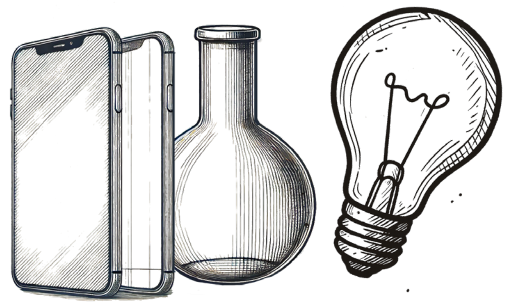
carbon black C  1 - 5 wt %

dicalcium phosphate $CaHPO_4$ 0.3 - 1.6 wt %

ORGANIC

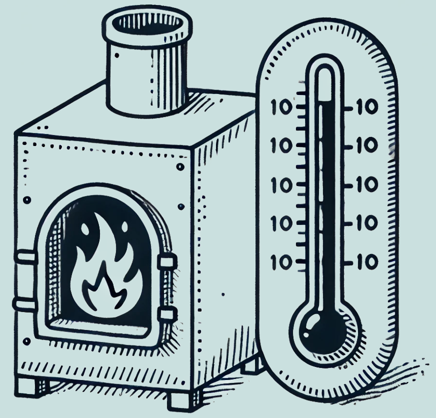
eggshells  1 - 5 wt %

What affects foaming?

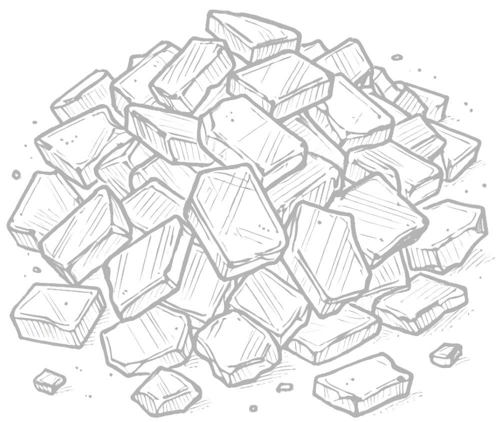


glass waste type

foaming agent

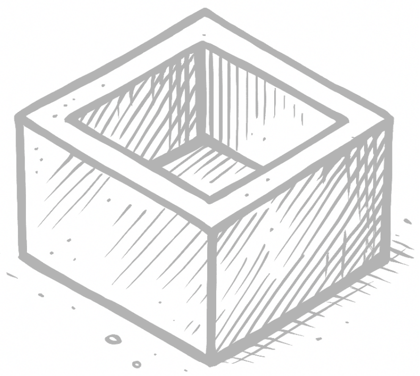


firing schedule



glass cullet size

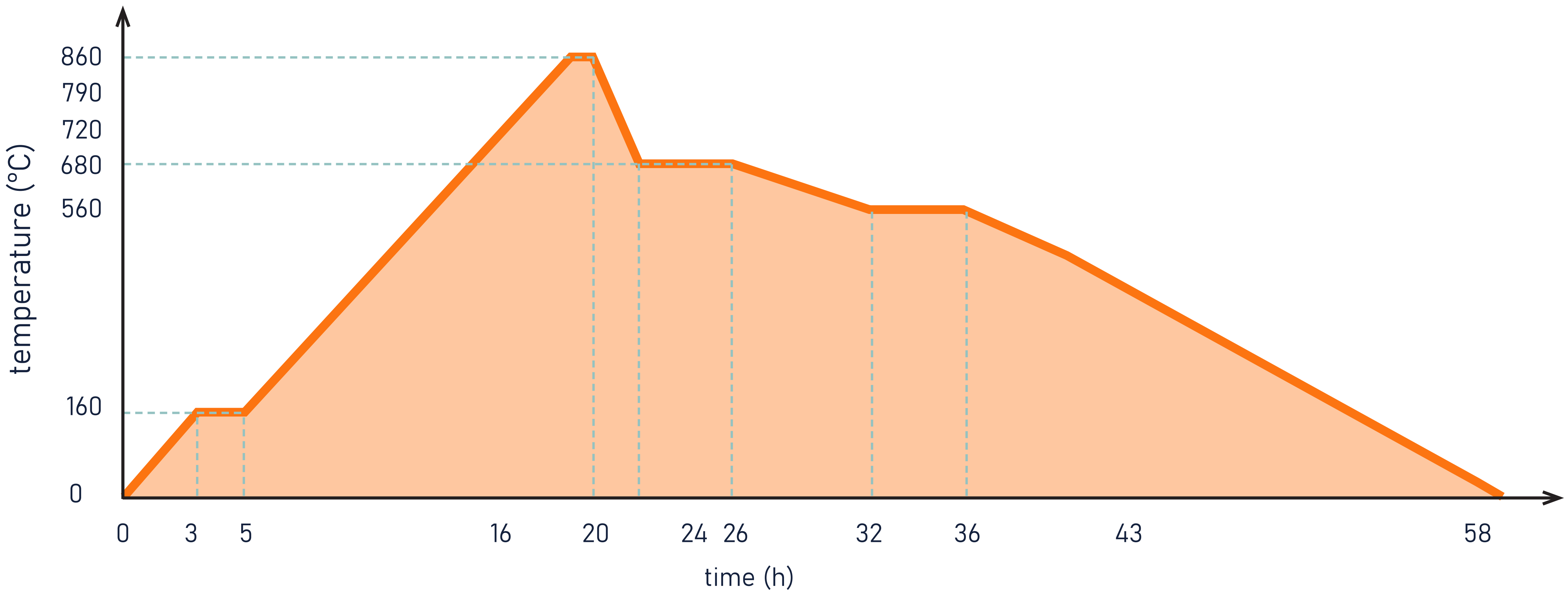
foaming agent
particle size



mould size/
geometry

tested parameters

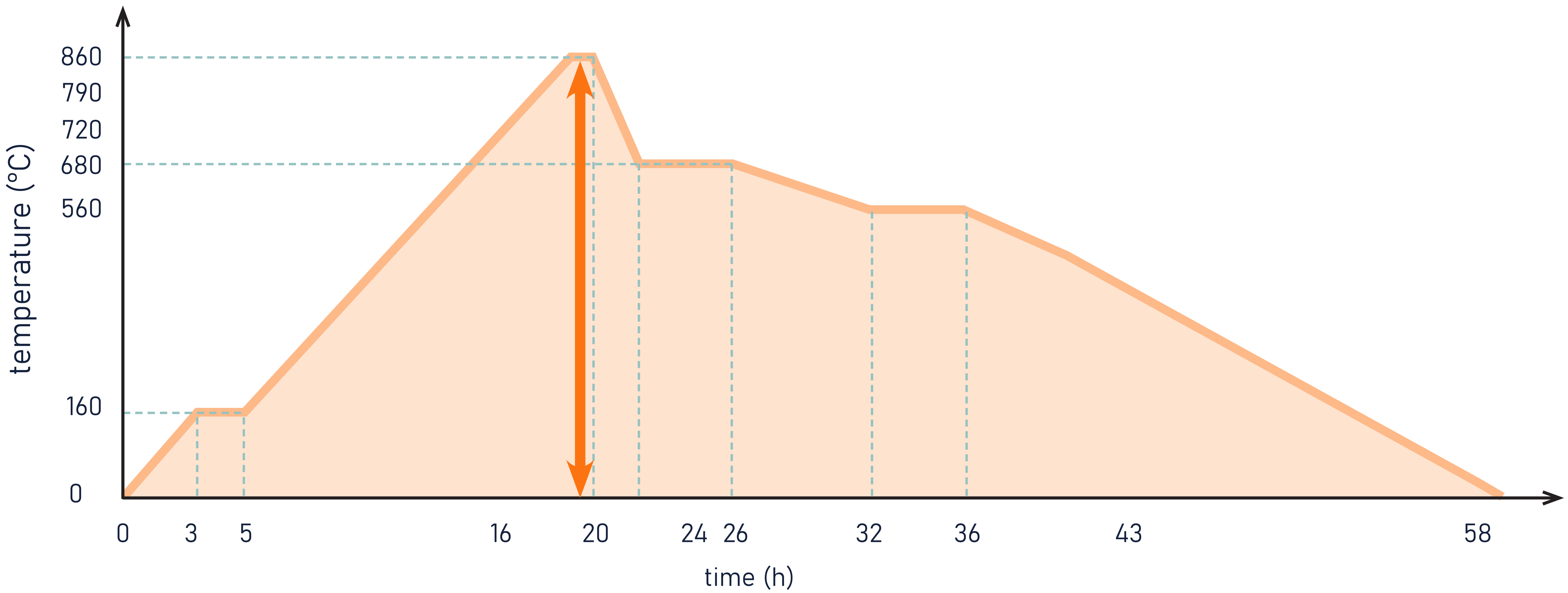
firing schedule



tested parameters

firing schedule

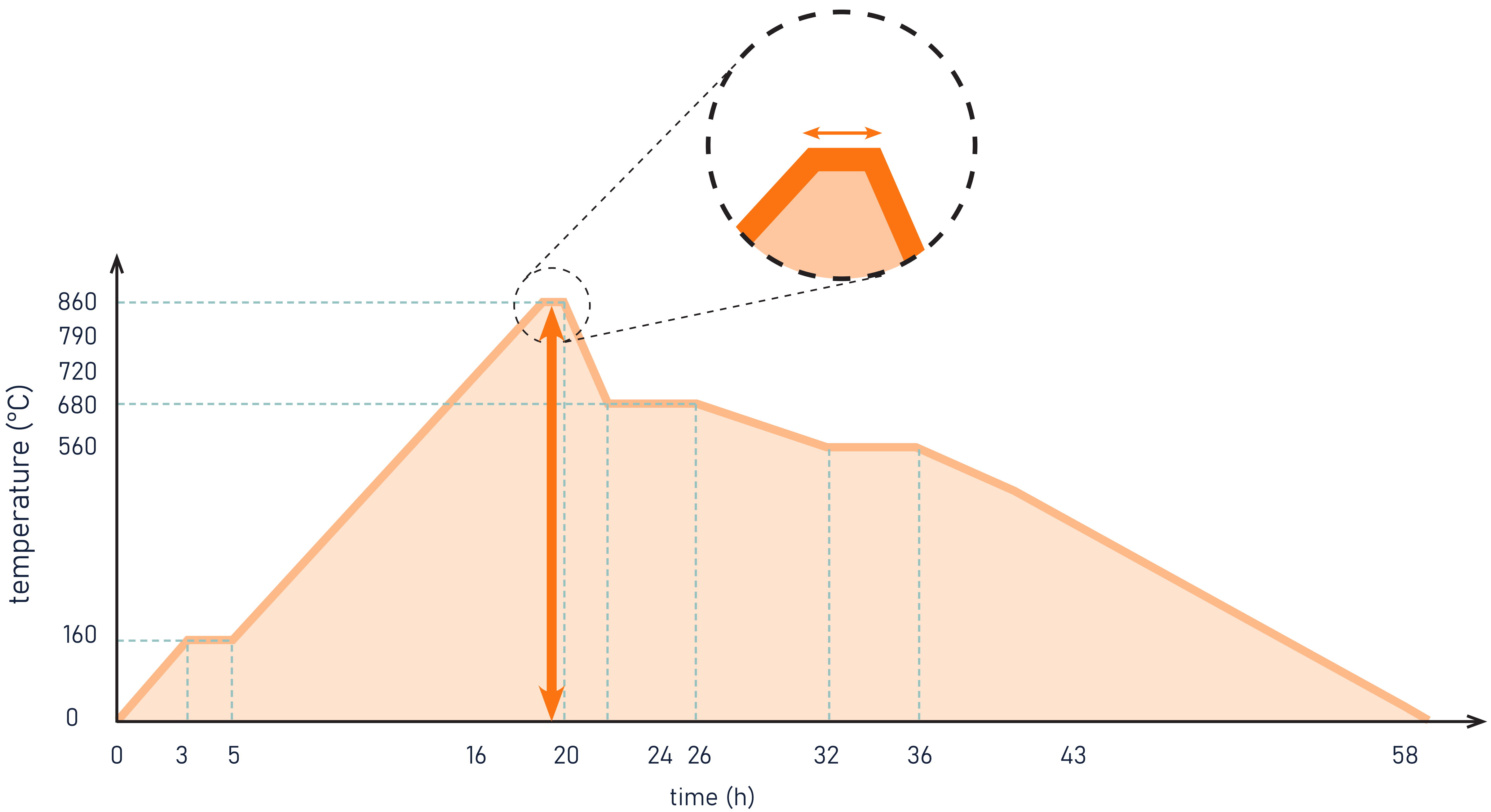
max temperature



tested parameters

firing schedule

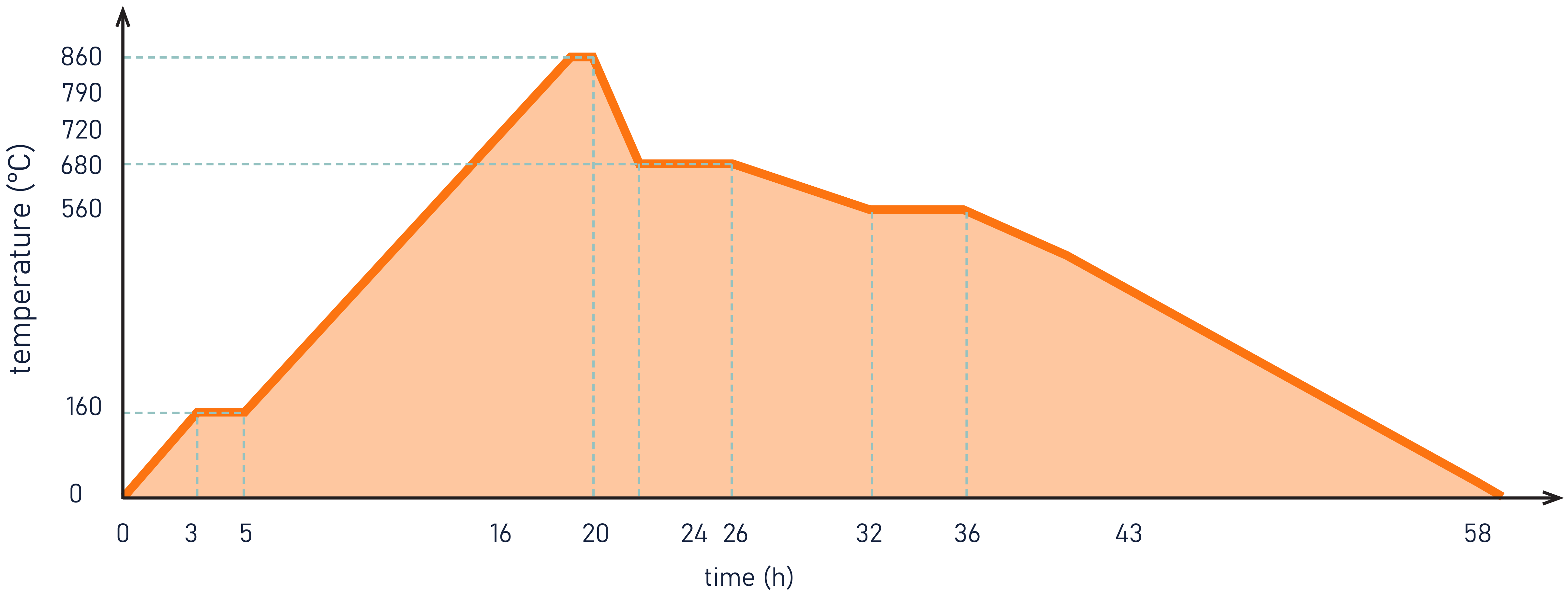
max temperature **dwell time**



tested parameters

firing schedule

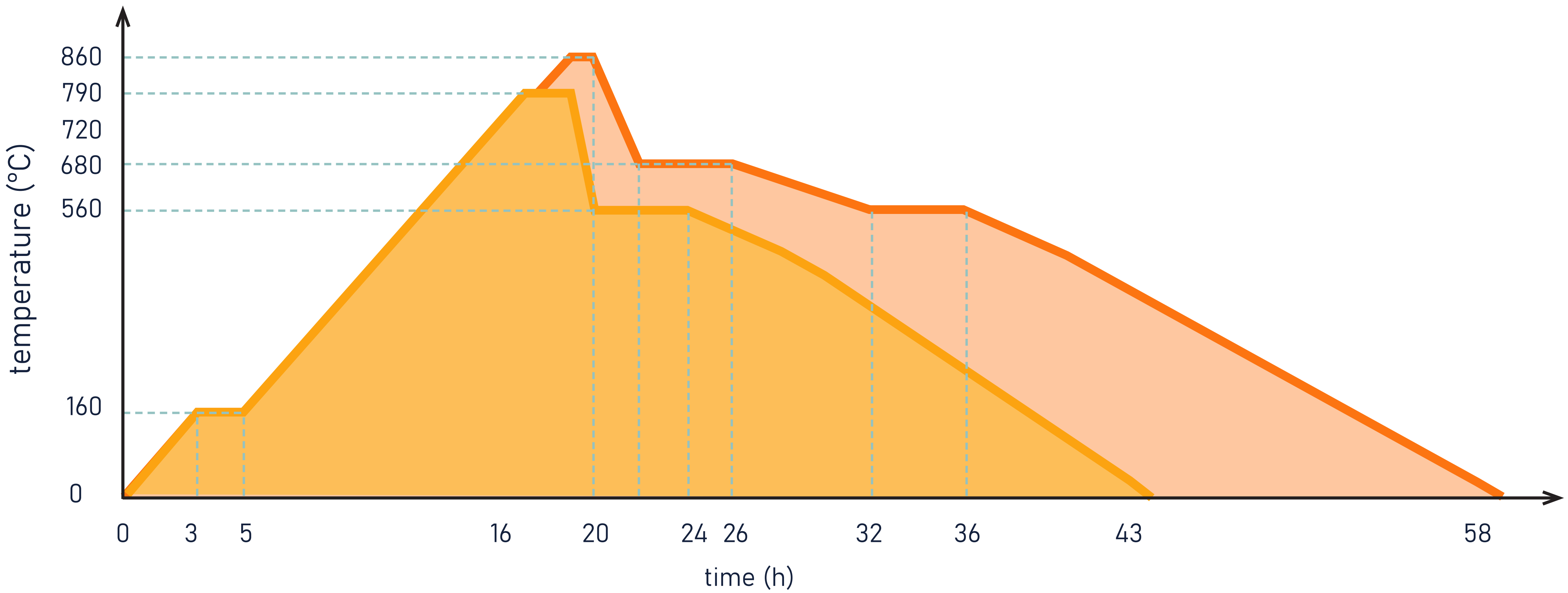
max temperature	**dwell time**
860°C	1h



tested parameters

firing schedule

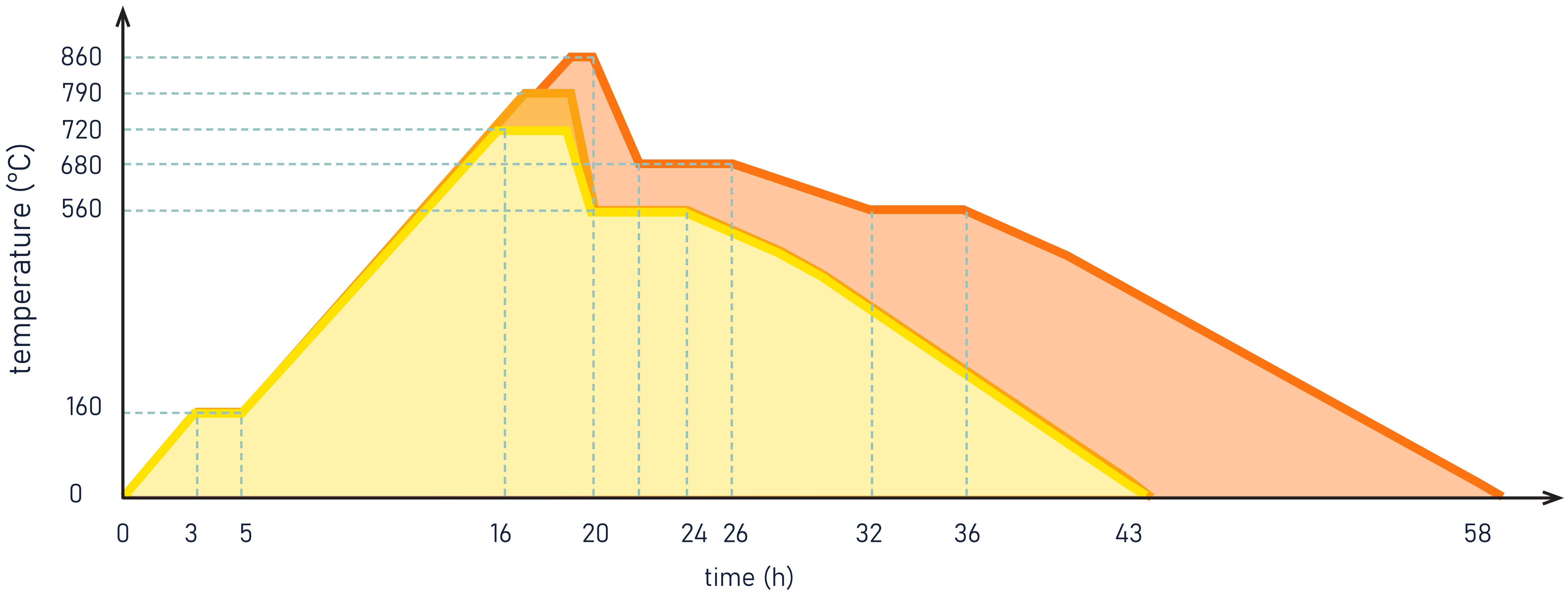
max temperature	dwell time
860°C	1h
790°C	2h

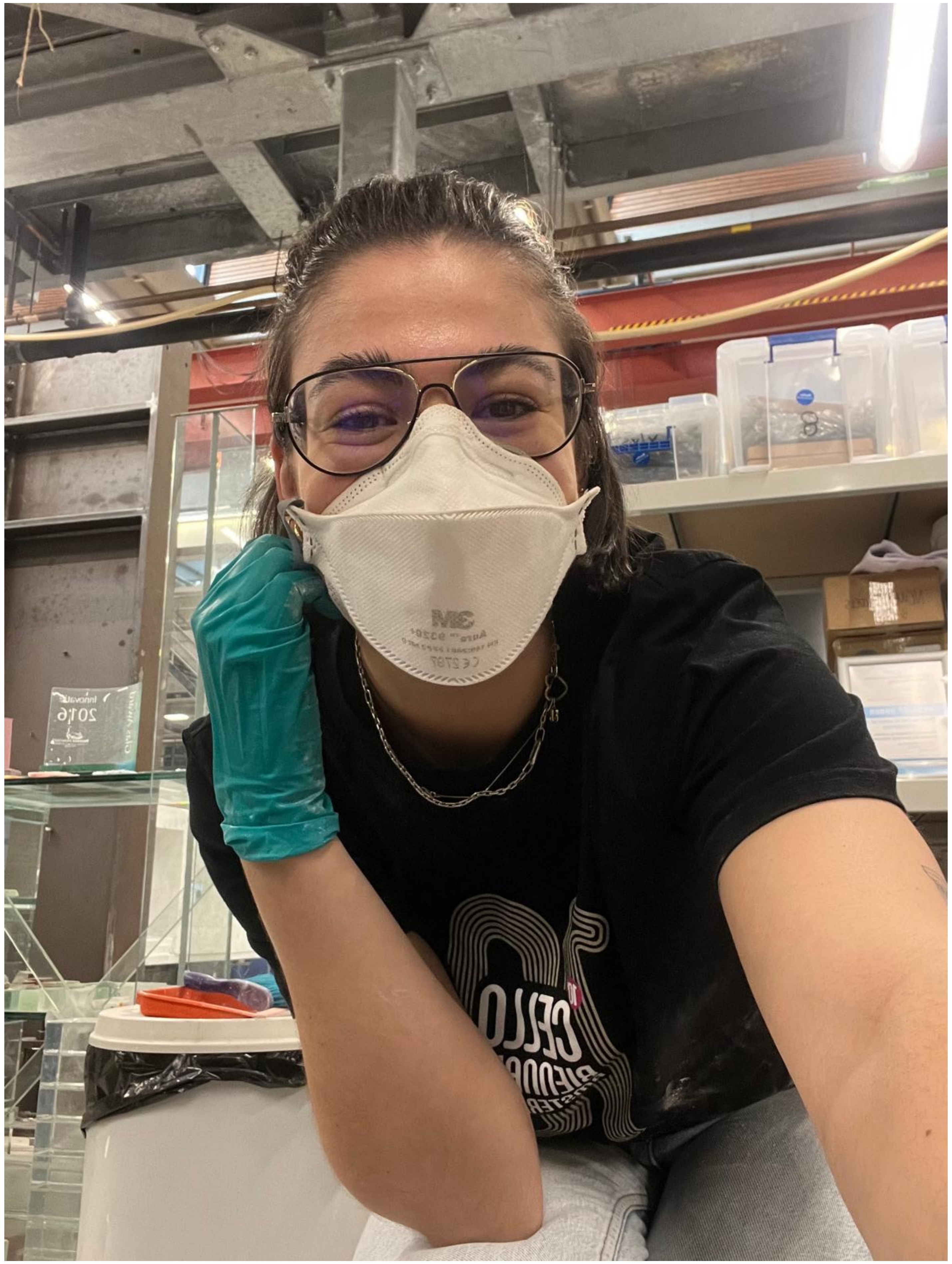


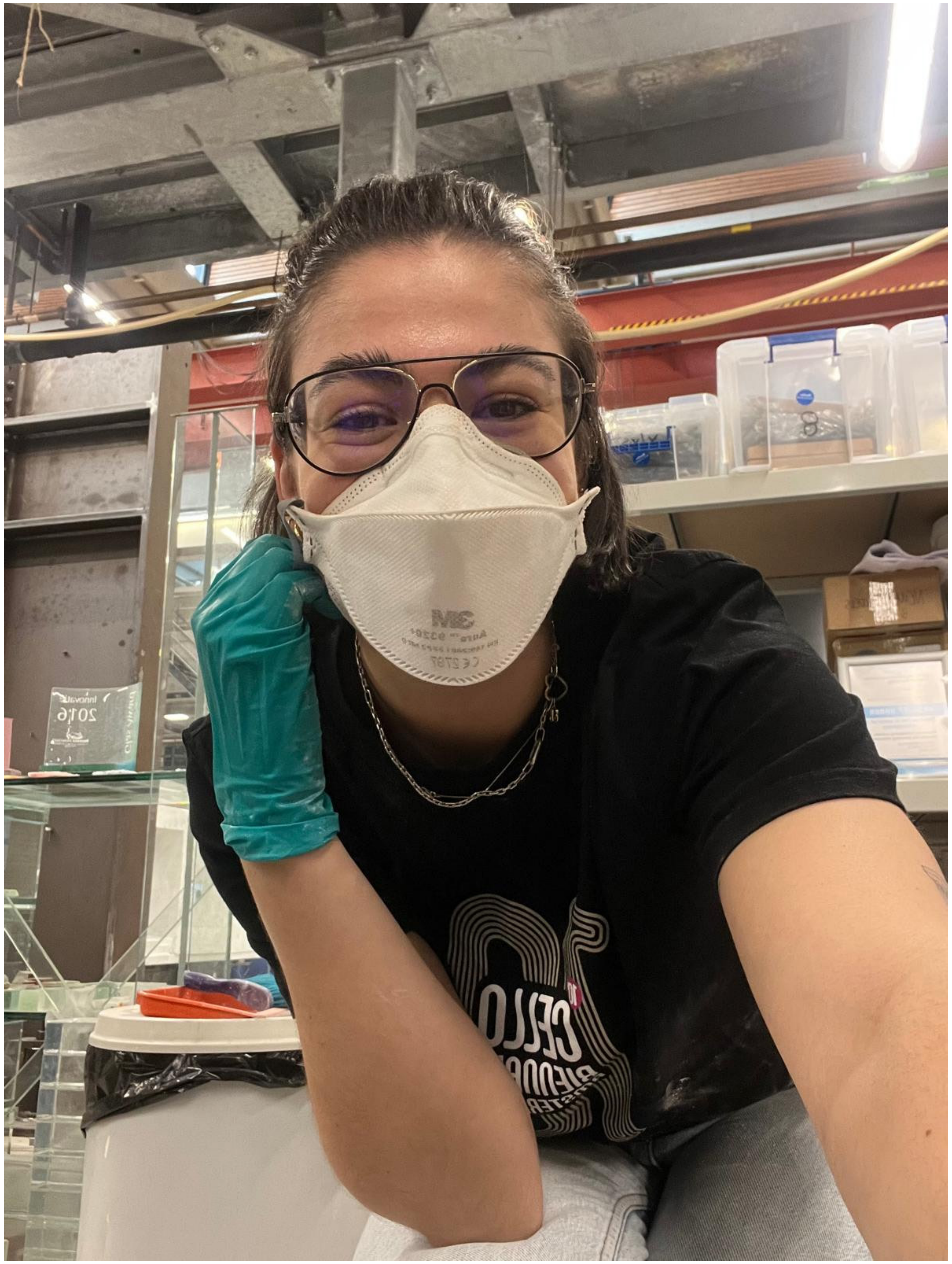
tested parameters

firing schedule

max temperature	dwell time
860°C	1h
790°C	2h
720°C	3h

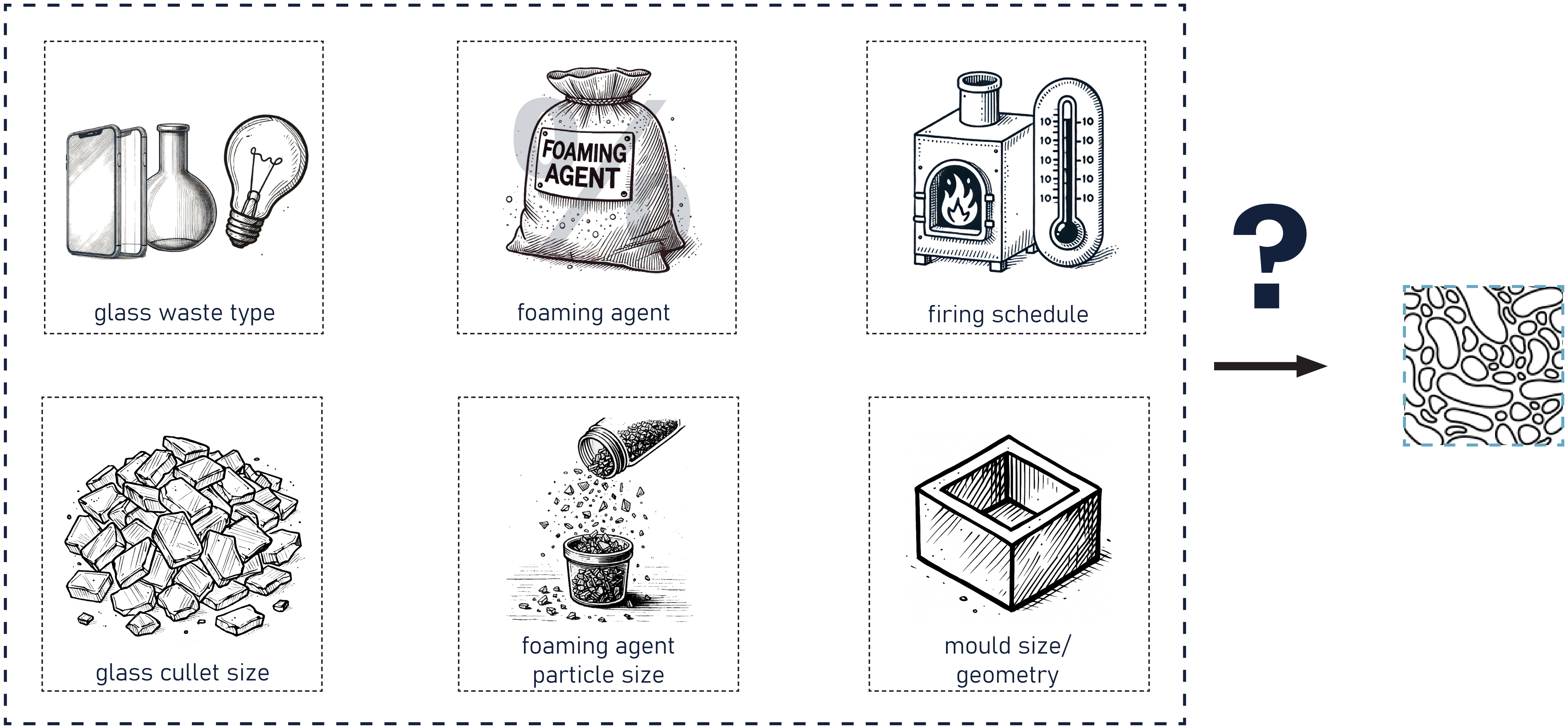



3M




SL2.5EST3

(How) do different fabrication parameters impact the porosity of the material?



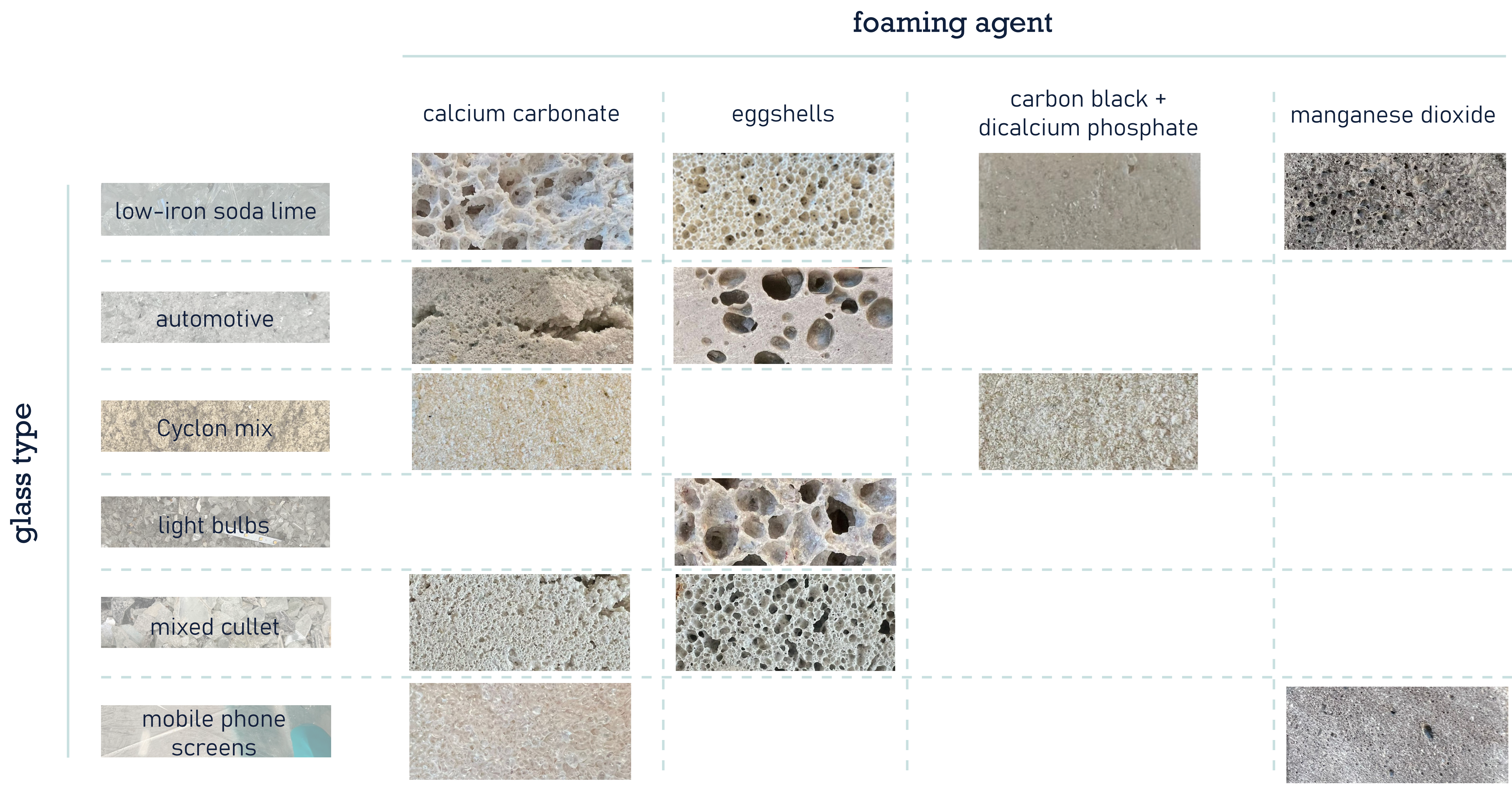
(How) do different fabrication parameters impact the porosity of the material?

foaming agent

glass type	calcium carbonate	eggshells	carbon black + dicalcium phosphate	manganese dioxide
low-iron soda lime	✓	✓	✗	✓
automotive	✓	✓		
Cyclon mix	✗		✗	
light bulbs		✓		
mixed cullet	✓	✓		
mobile phone screens	✗			✗

foaming agent

glass type	calcium carbonate	eggshells	carbon black + dicalcium phosphate	manganese dioxide
low-iron soda lime	✓	✓		✓
automotive	✓	✓		
Cyclon mix				
light bulbs		✓		
mixed cullet	✓	✓		
mobile phone screens				


foaming agent
calcium carbonate
eggshells
carbon black + dicalcium phosphate
manganese dioxide
glass type
low-iron soda lime
automotive
Cyclon mix
light bulbs
mixed cullet
mobile phone screens

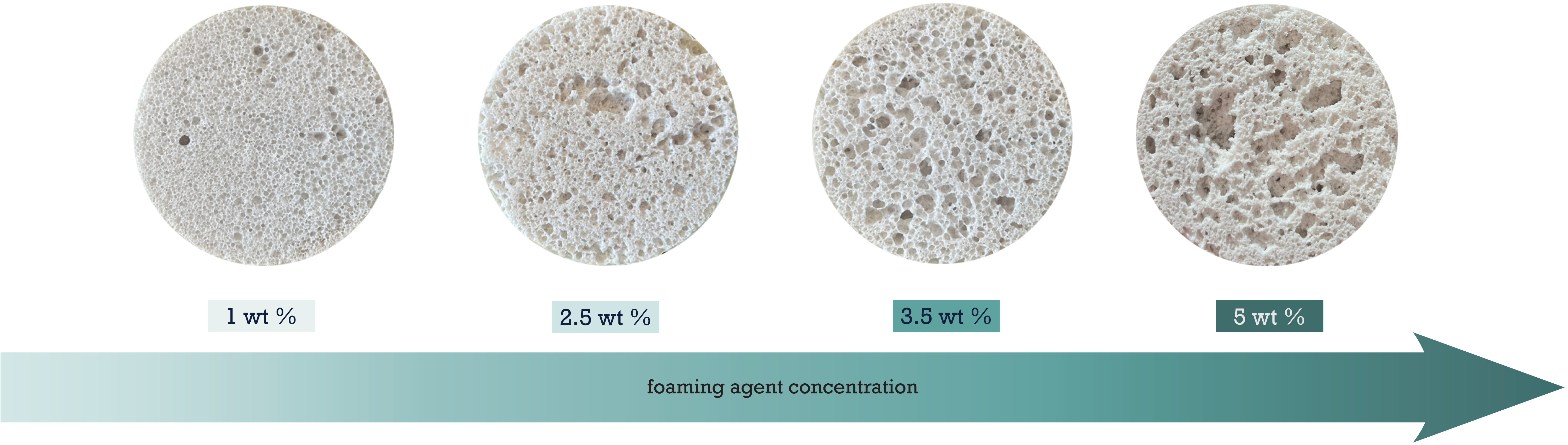
(How) do different fabrication parameters impact the porosity of the material?

(How) do different fabrication parameters impact the porosity of the material?

foaming agent concentration

soda lime + calcium carbonate

790°C



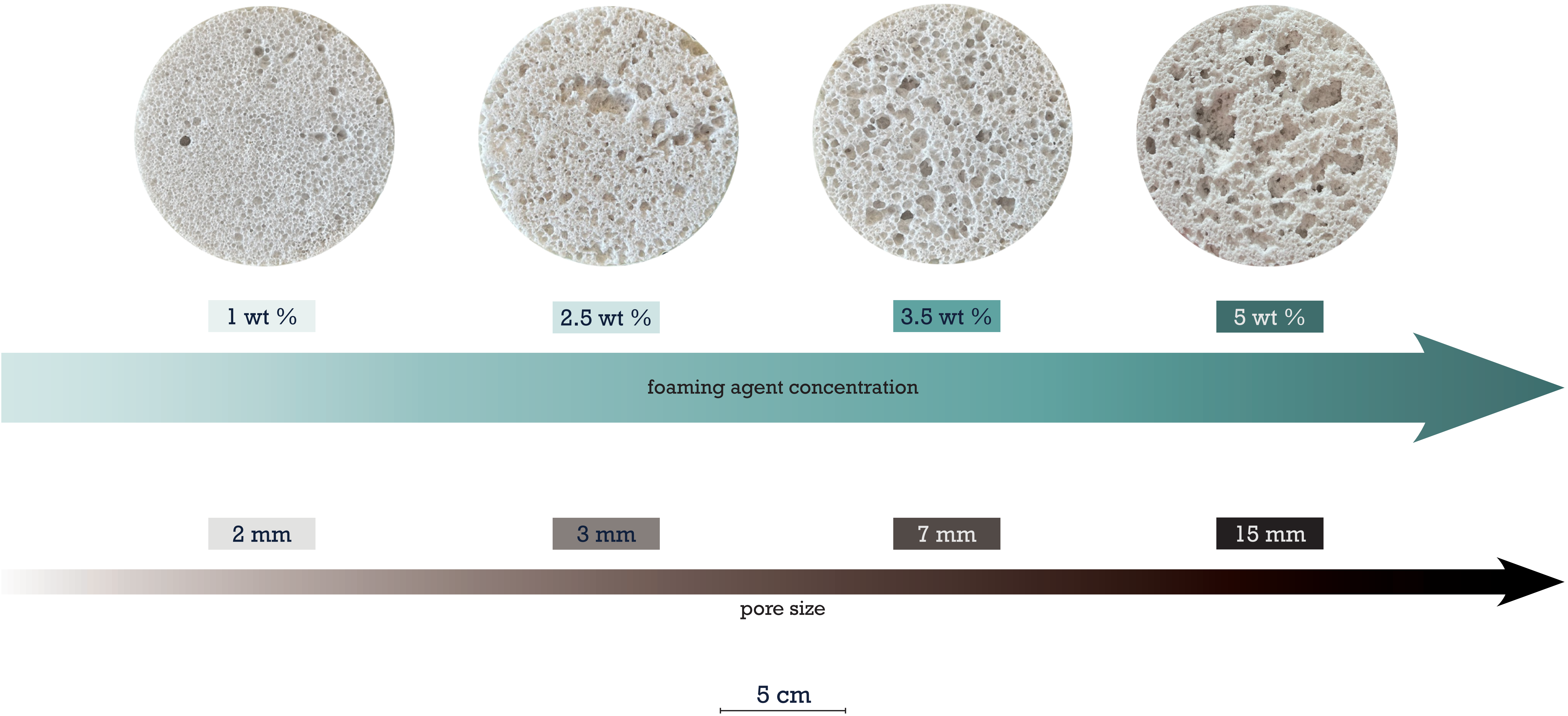
5 cm

(How) do different fabrication parameters impact the porosity of the material?

foaming agent concentration

soda lime + calcium carbonate

790°C



(How) do different fabrication parameters impact the porosity of the material?

foaming agent concentration

light bulbs + eggshells

790°C

1 wt %

2.5 wt %

foaming agent concentration

5 cm

(How) do different fabrication parameters impact the porosity of the material?

foaming agent concentration

light bulbs + eggshells

790°C

1 wt %

2.5 wt %

foaming agent concentration

14 mm

11 mm

pore size

5 cm

(How) do different fabrication parameters impact the porosity of the material?

foaming agent type

calcium carbonate vs. eggshells

	eggshells	pure calcium carbonate
low-iron soda lime + 5 wt % foaming agent		

5 cm

(How) do different fabrication parameters impact the porosity of the material?

foaming agent type

calcium carbonate vs. eggshells

low-iron soda lime +
5 wt % foaming agent

eggshells

pure calcium carbonate

5 cm

(How) do different fabrication parameters impact the porosity of the material?

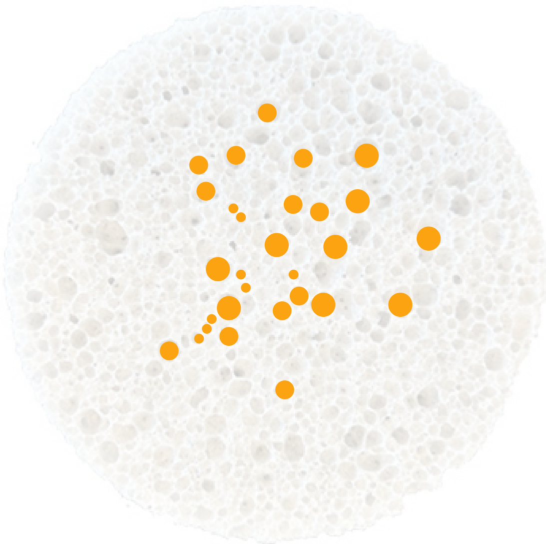
foaming agent type

calcium carbonate vs. eggshells

eggshells

pure calcium carbonate

low-iron soda lime +
5 wt % foaming agent

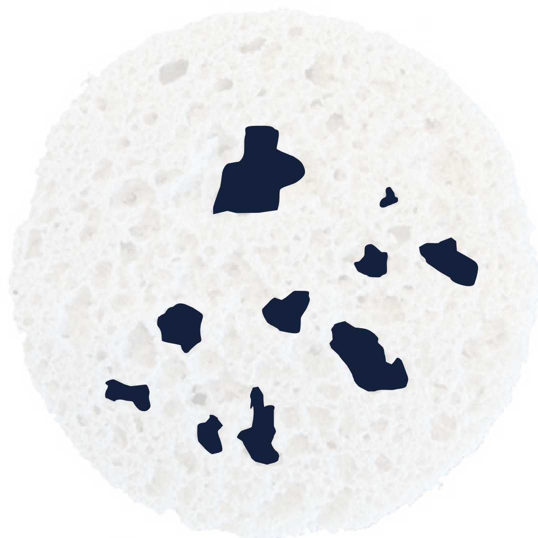
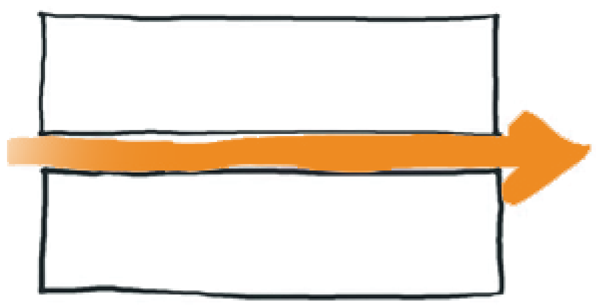
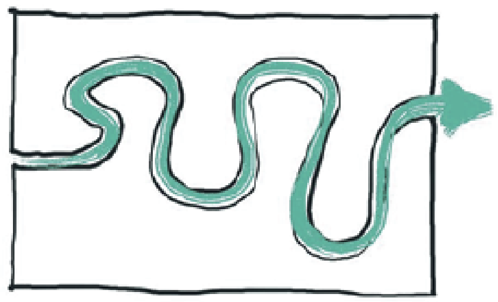


5 cm

(How) do different fabrication parameters impact the porosity of the material?

foaming agent type

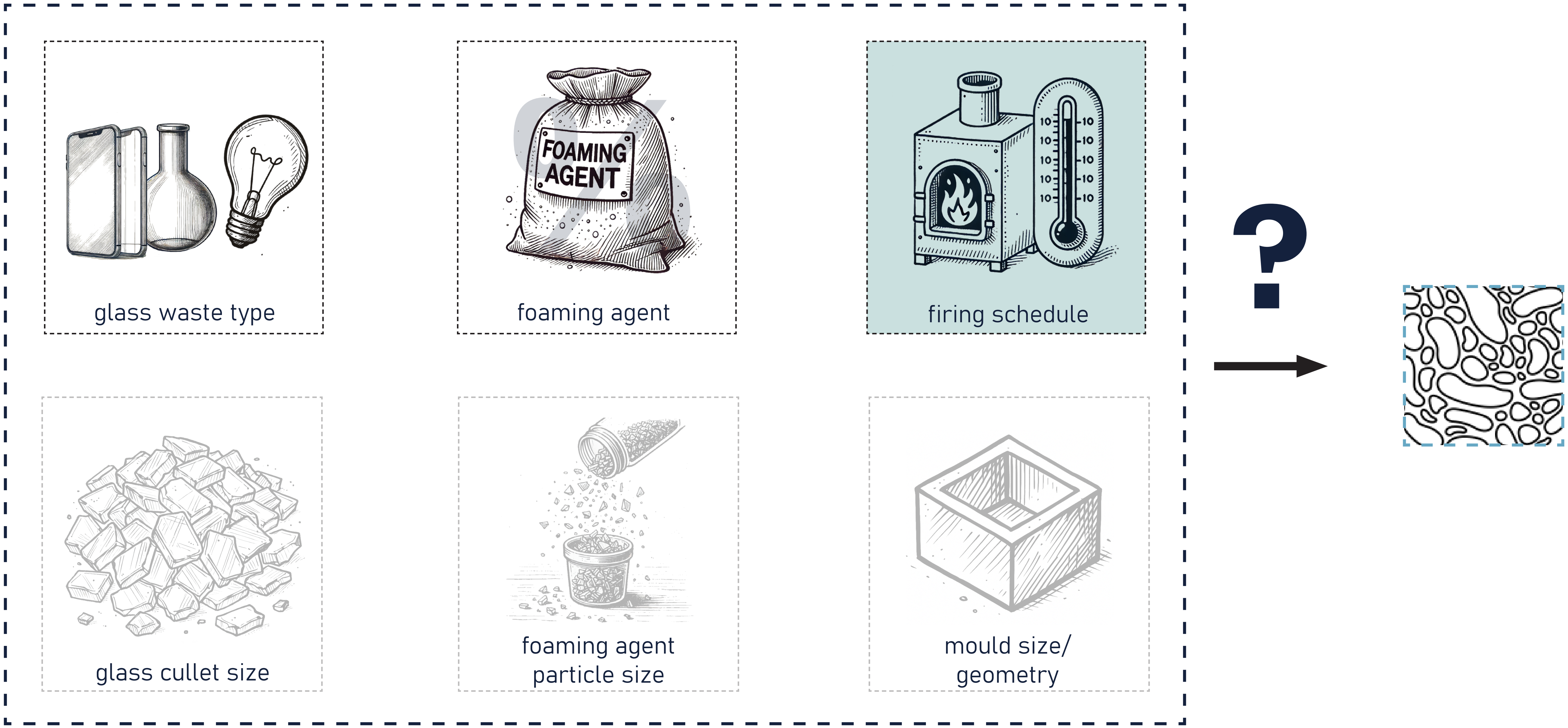
calcium carbonate vs. eggshells

	eggshells	pure calcium carbonate
low-iron soda lime + 5 wt % foaming agent		
		

tortuosity

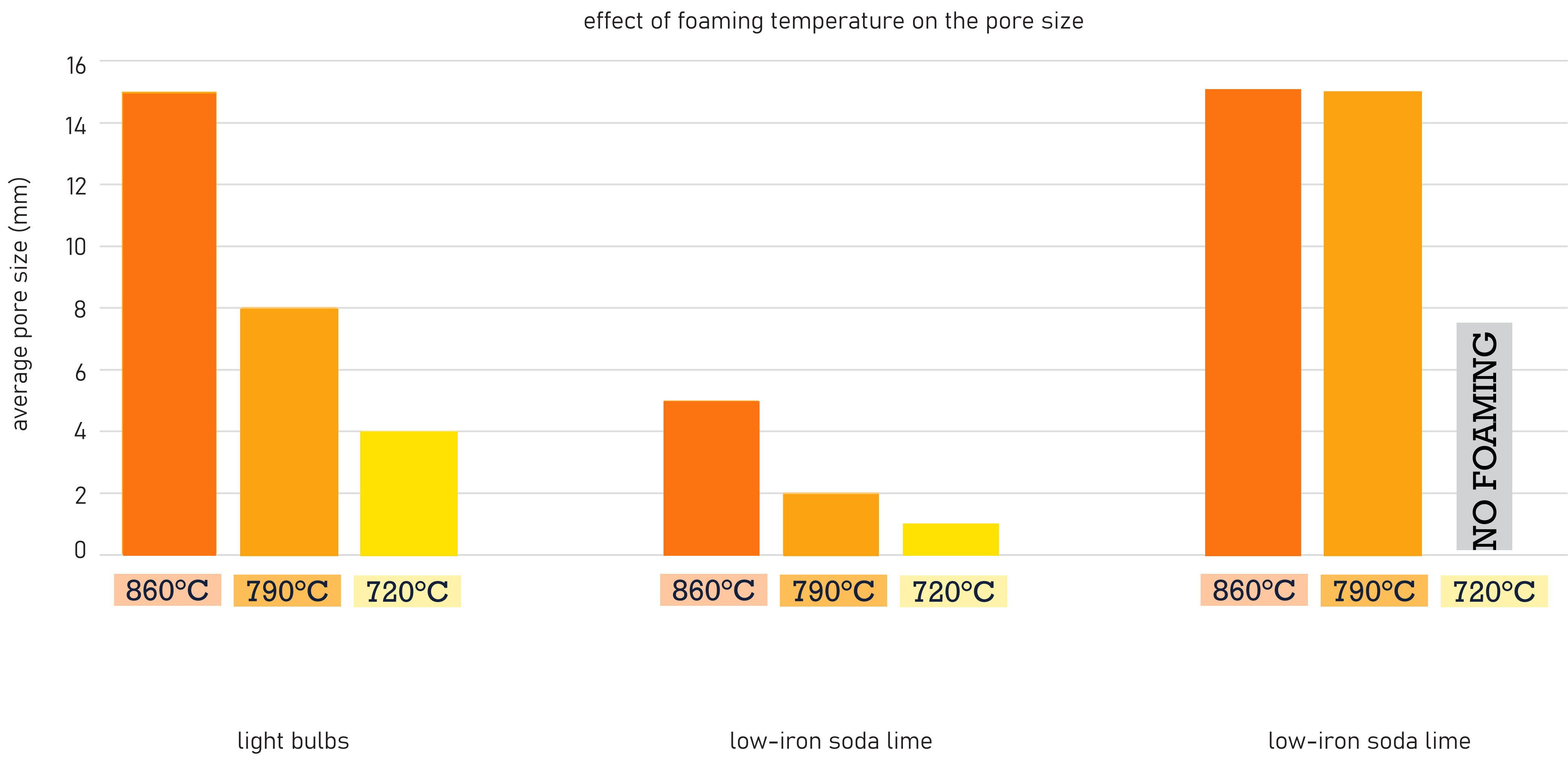
5 cm

(How) do different fabrication parameters impact the porosity of the material?



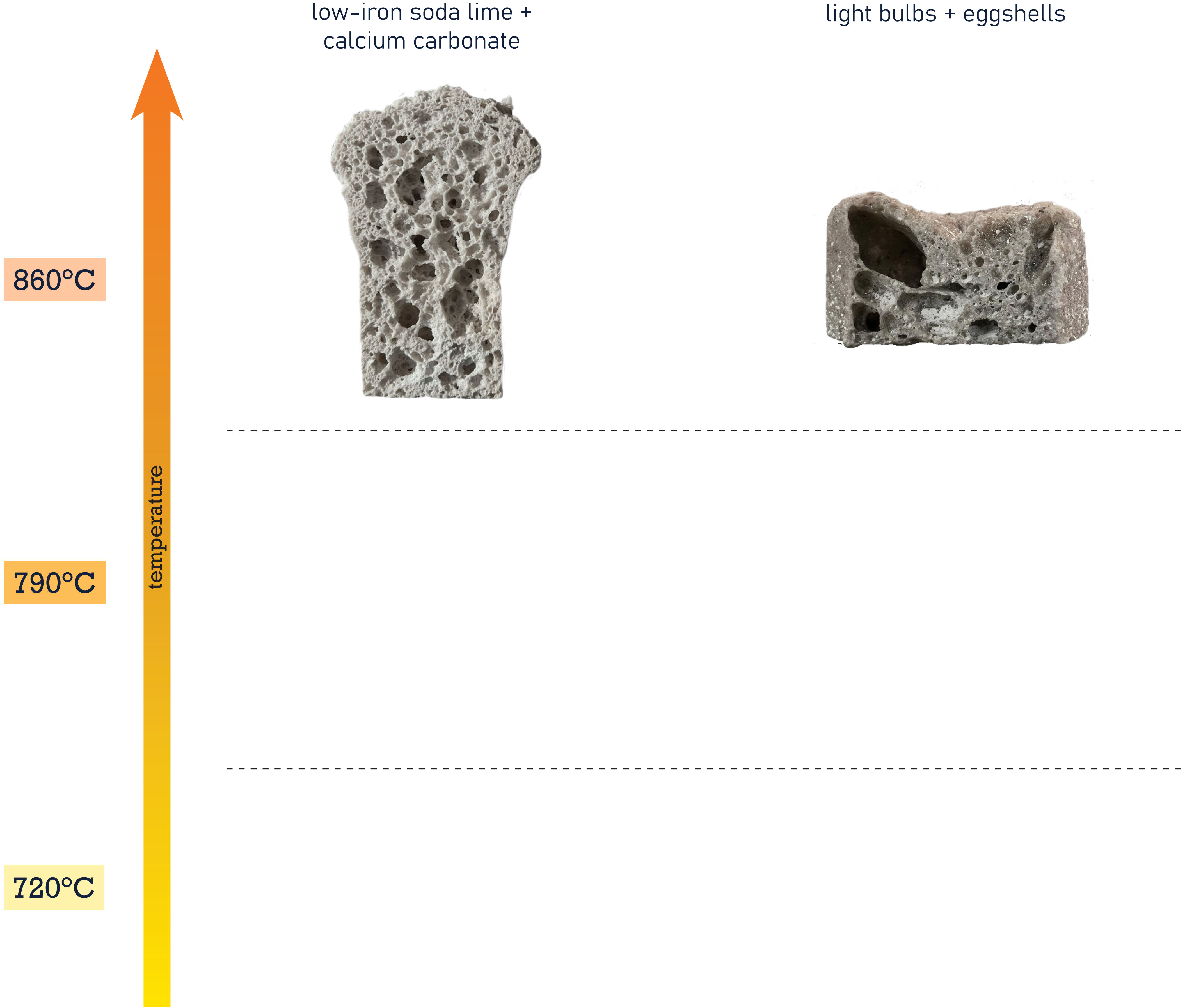
(How) do different fabrication parameters impact the porosity of the material?

temperature



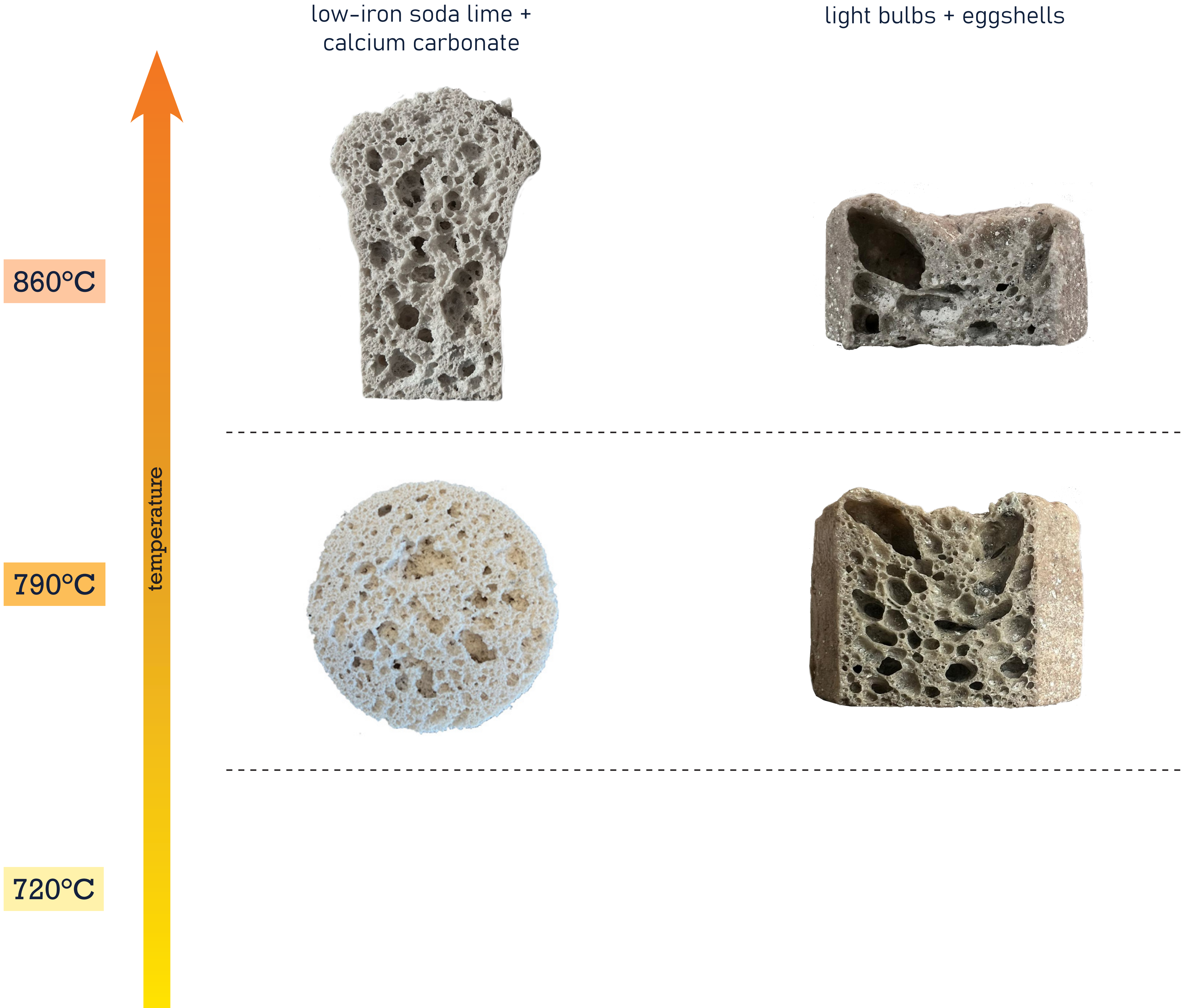
(How) do different fabrication parameters impact the porosity of the material?

temperature



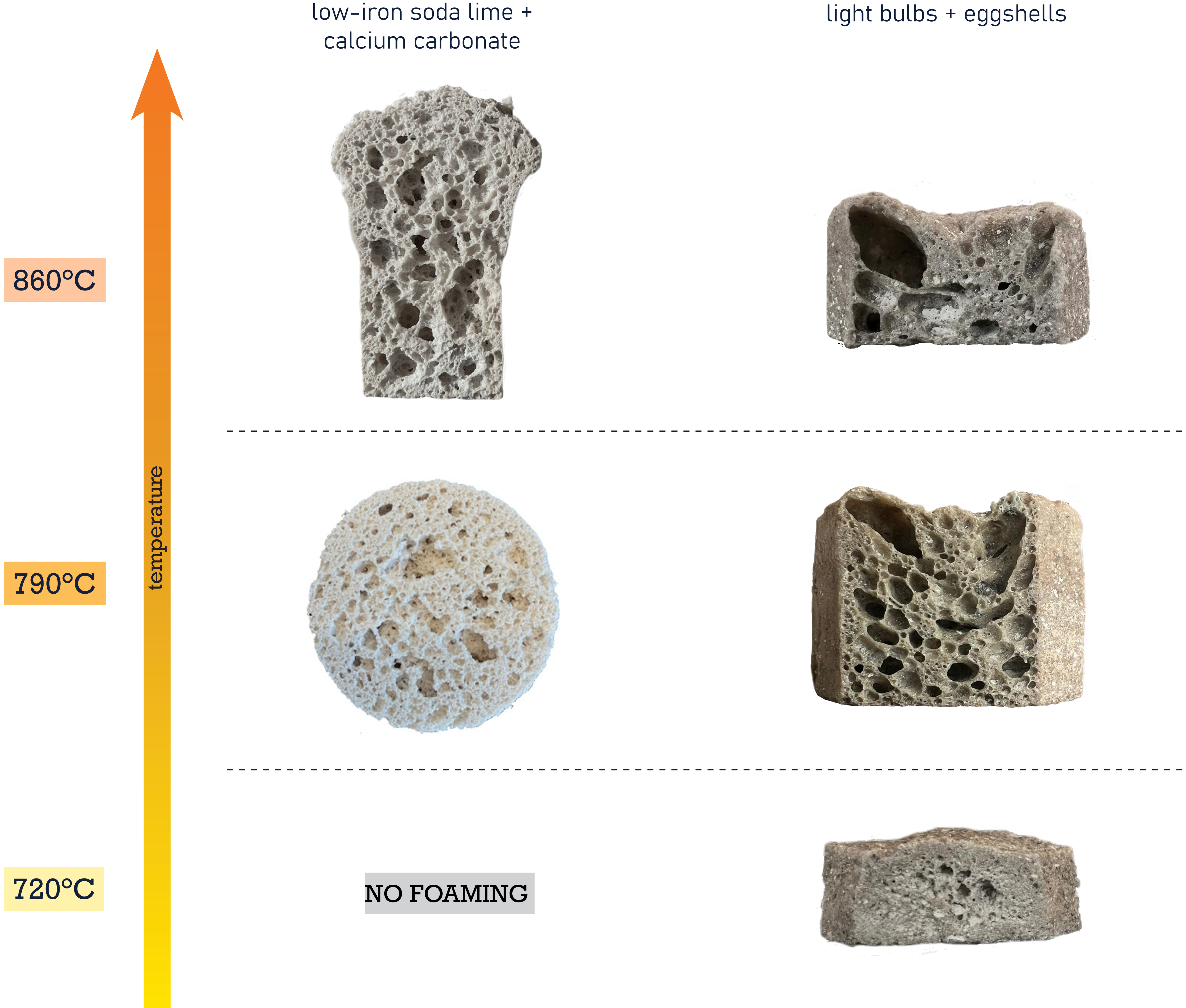
(How) do different fabrication parameters impact the porosity of the material?

temperature



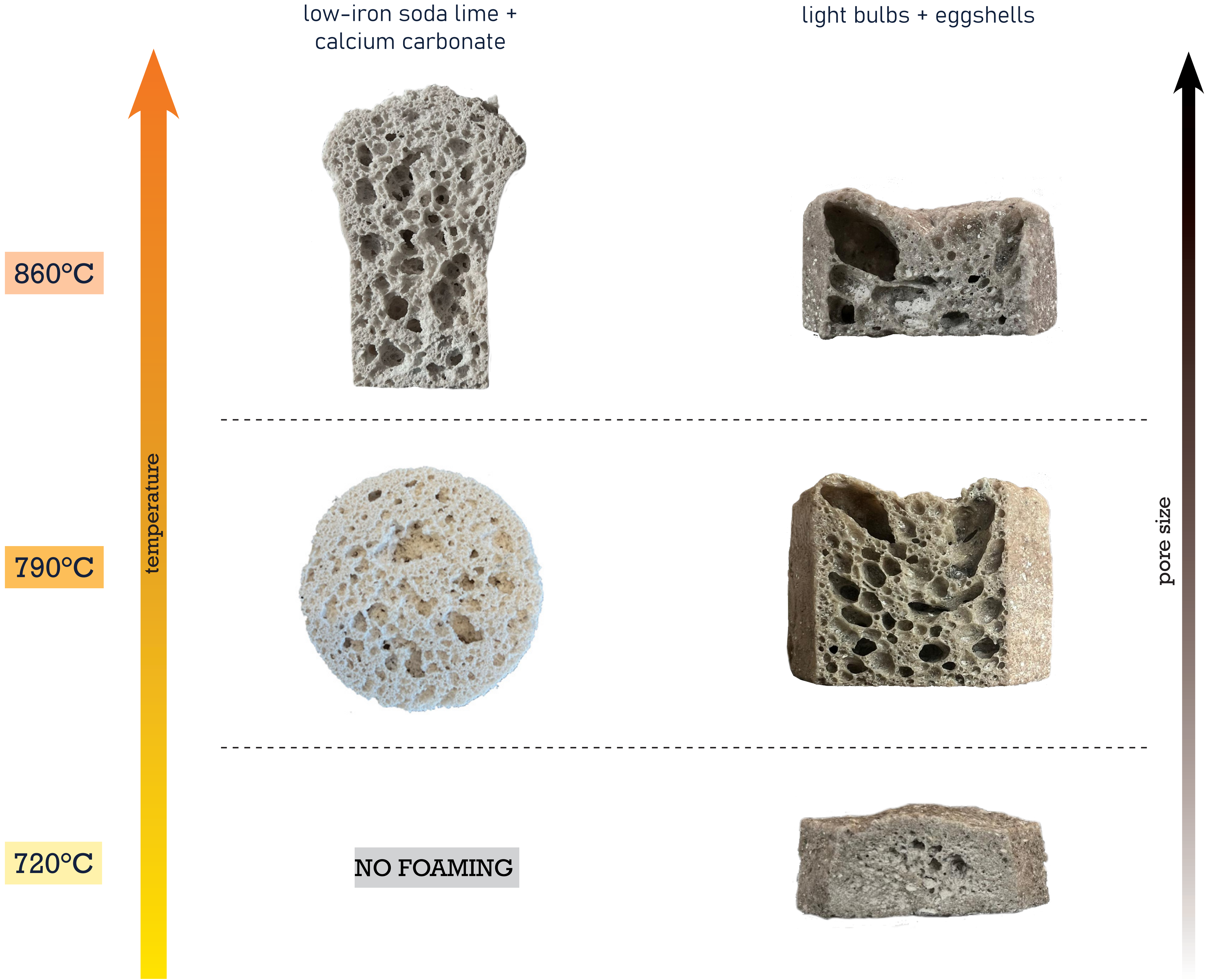
(How) do different fabrication parameters impact the porosity of the material?

temperature

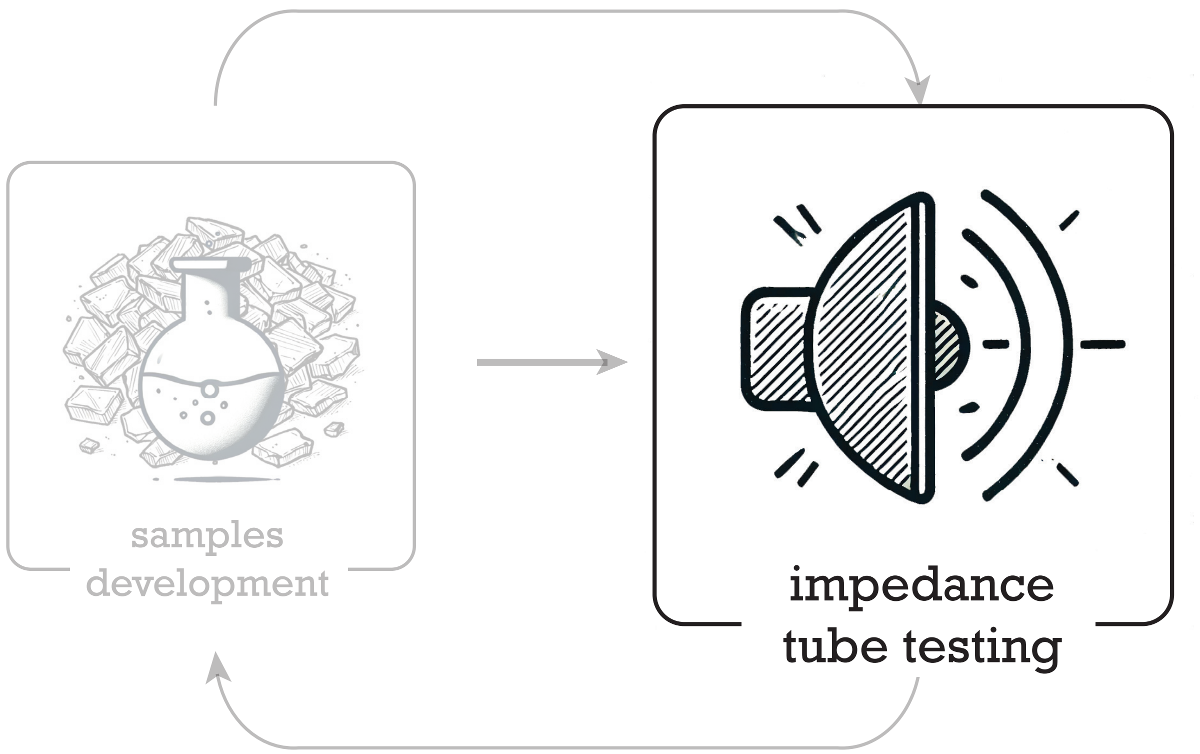


(How) do different fabrication parameters impact the porosity of the material?

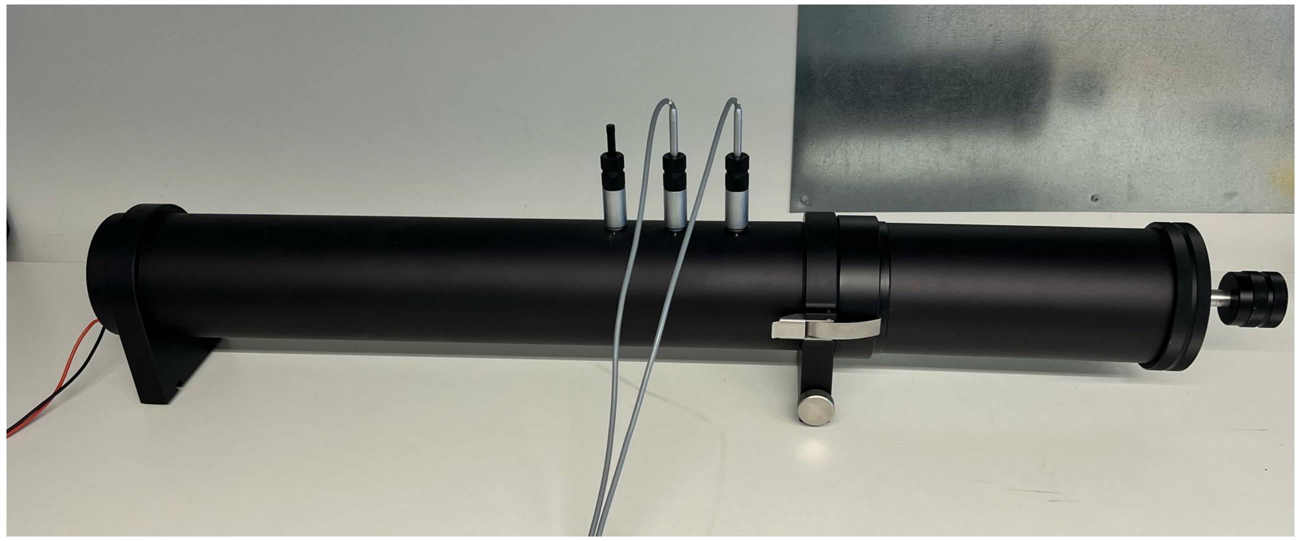
temperature



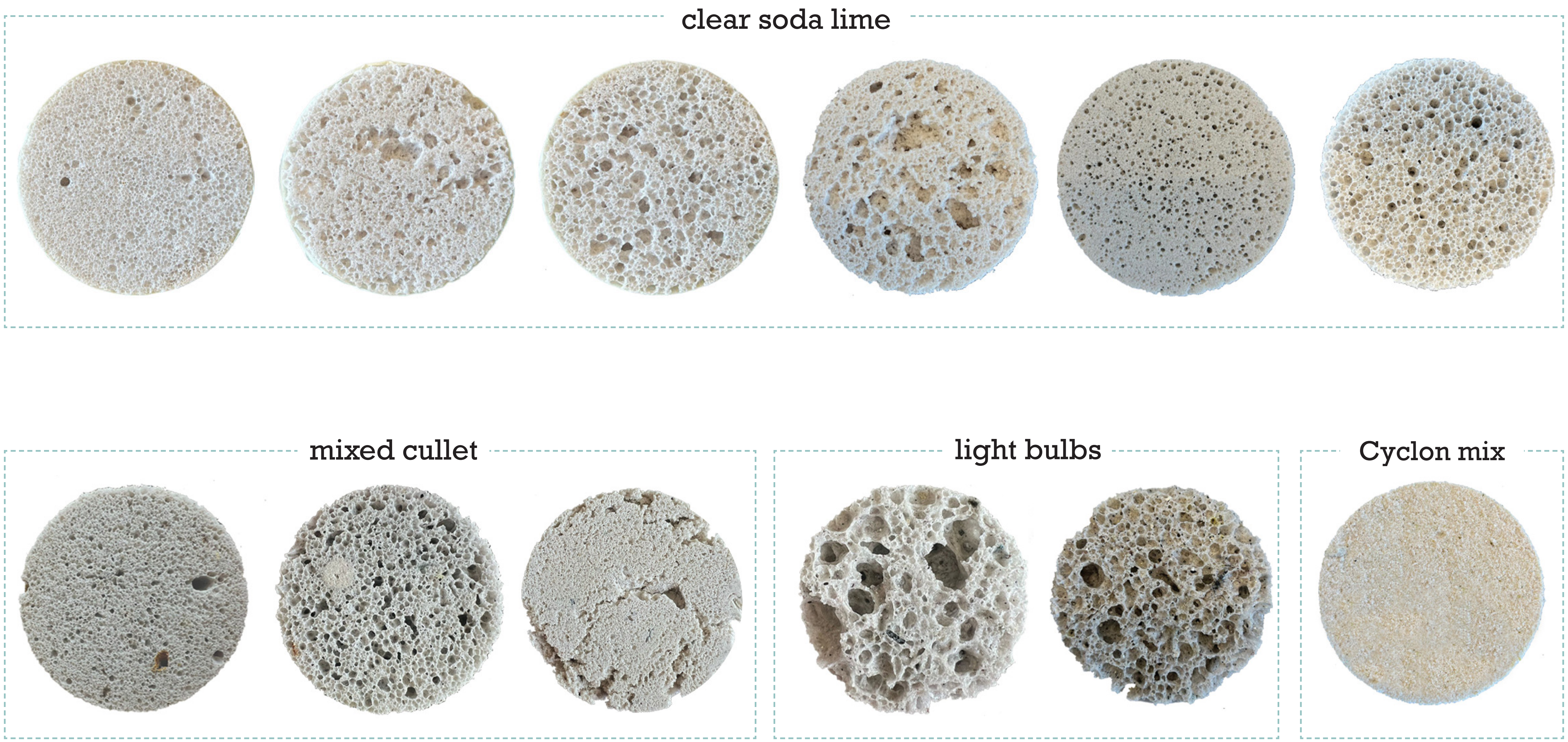
performance



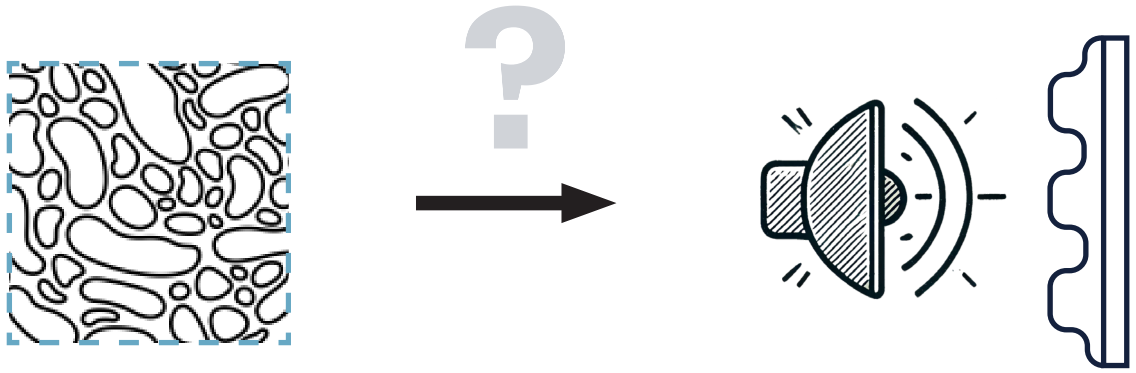
50 - 1600 Hz



1600 - 6400 Hz

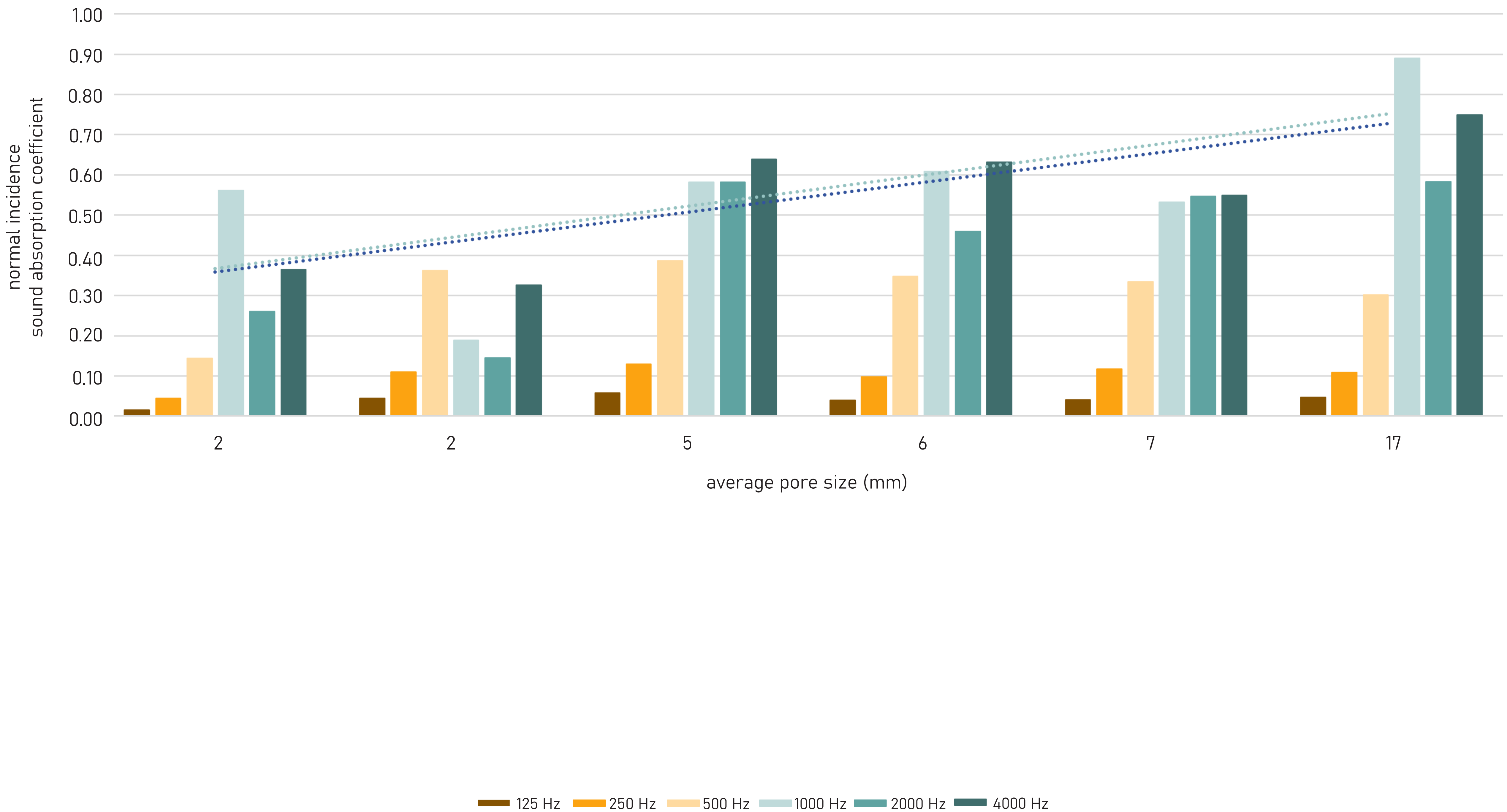

clear soda lime
mixed cullet
light bulbs
Cyclon mix

What are the effects of the material's **porosity** on its acoustic properties?



What are the effects of the material's porosity on its acoustic properties?

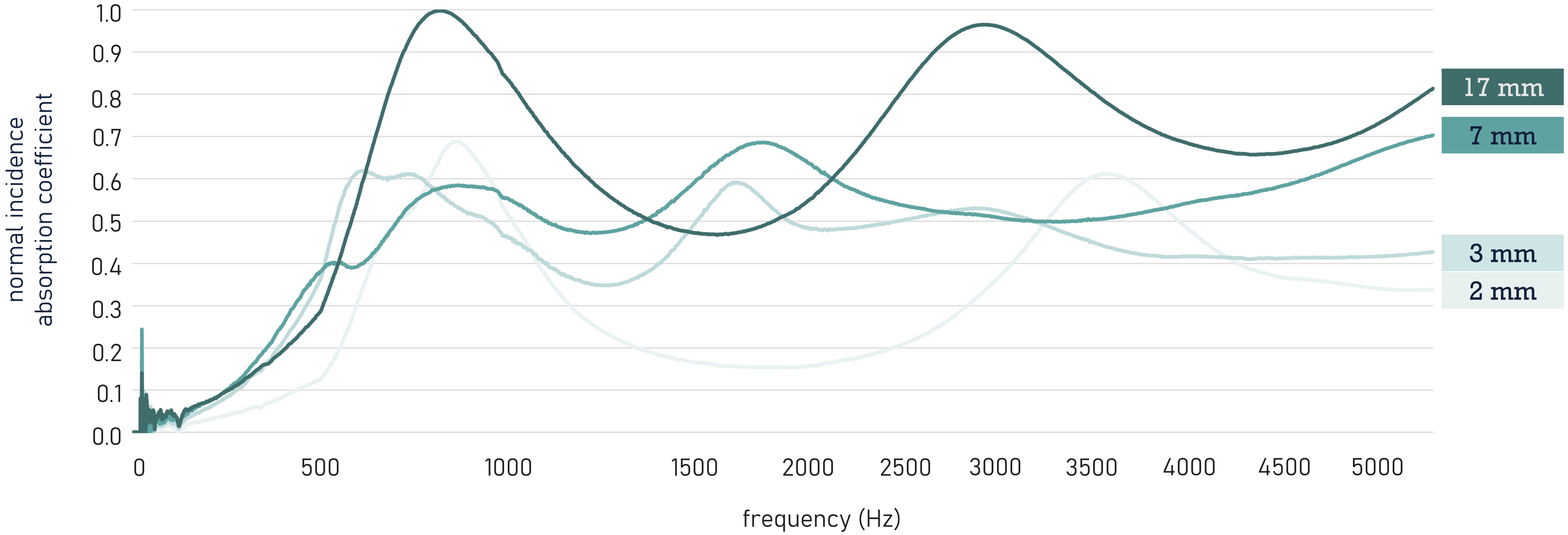
pore size



What are the effects of the material's **porosity** on its acoustic properties?

clear soda lime

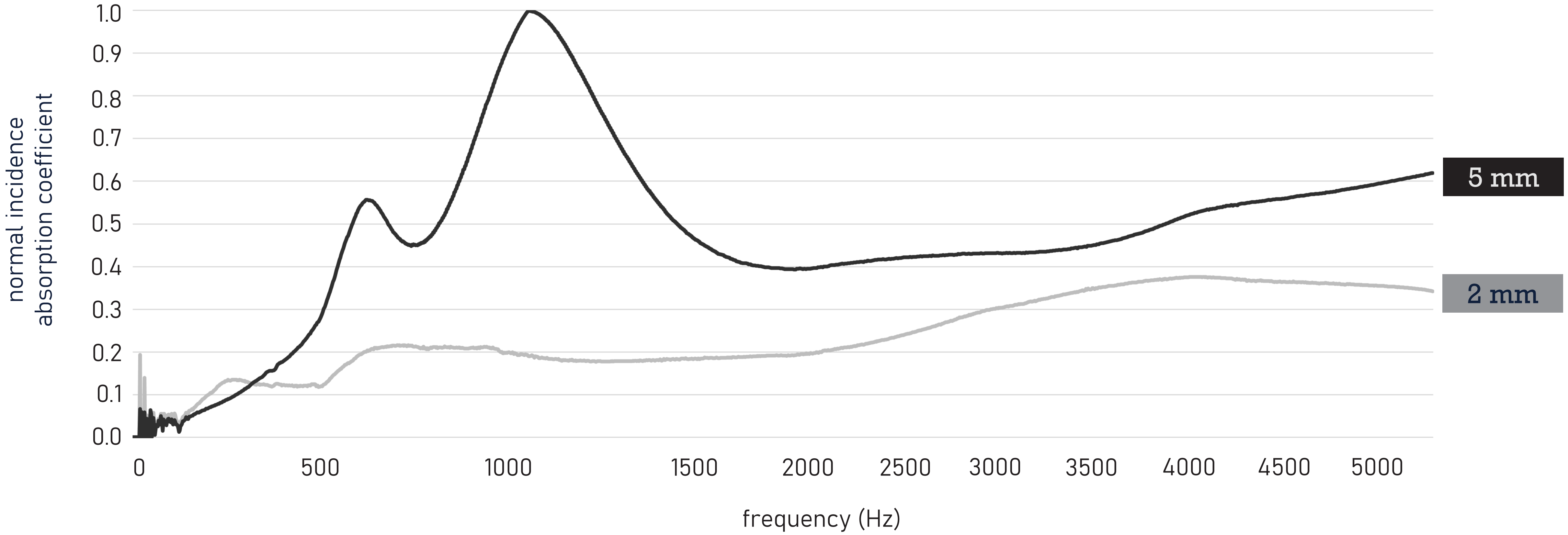
pore size



What are the effects of the material's porosity on its acoustic properties?

mixed cullet

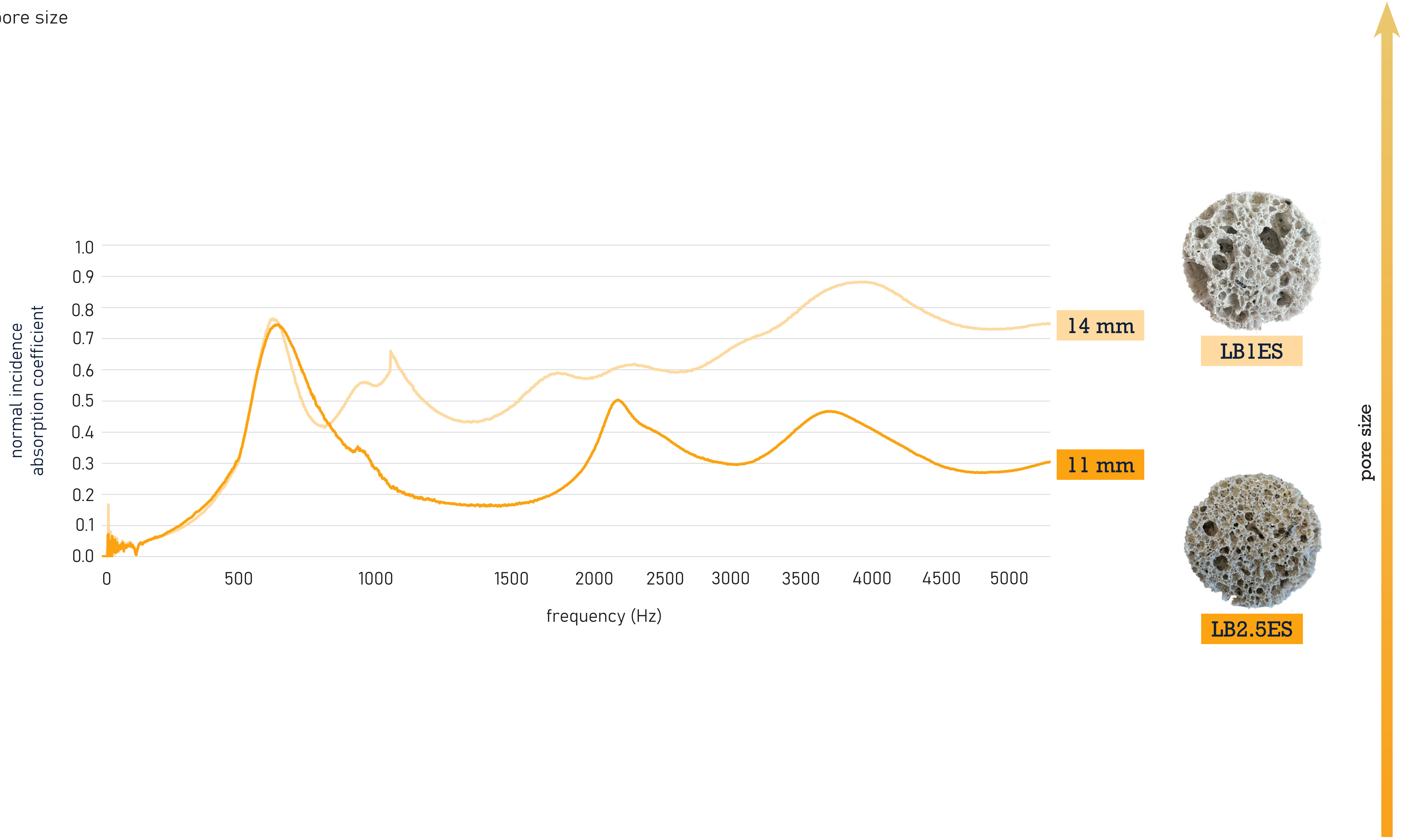
pore size



What are the effects of the material's **porosity** on its acoustic properties?

light bulbs

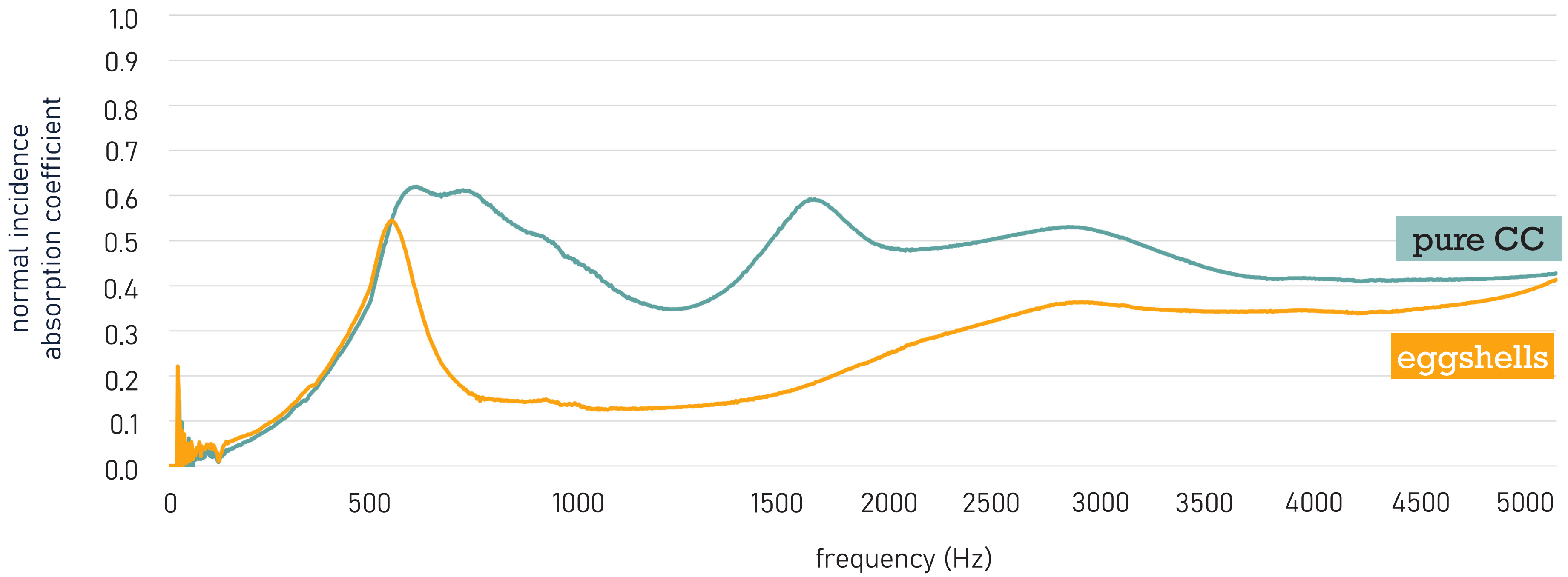
pore size



What are the effects of the material's porosity on its acoustic properties?

clear soda lime

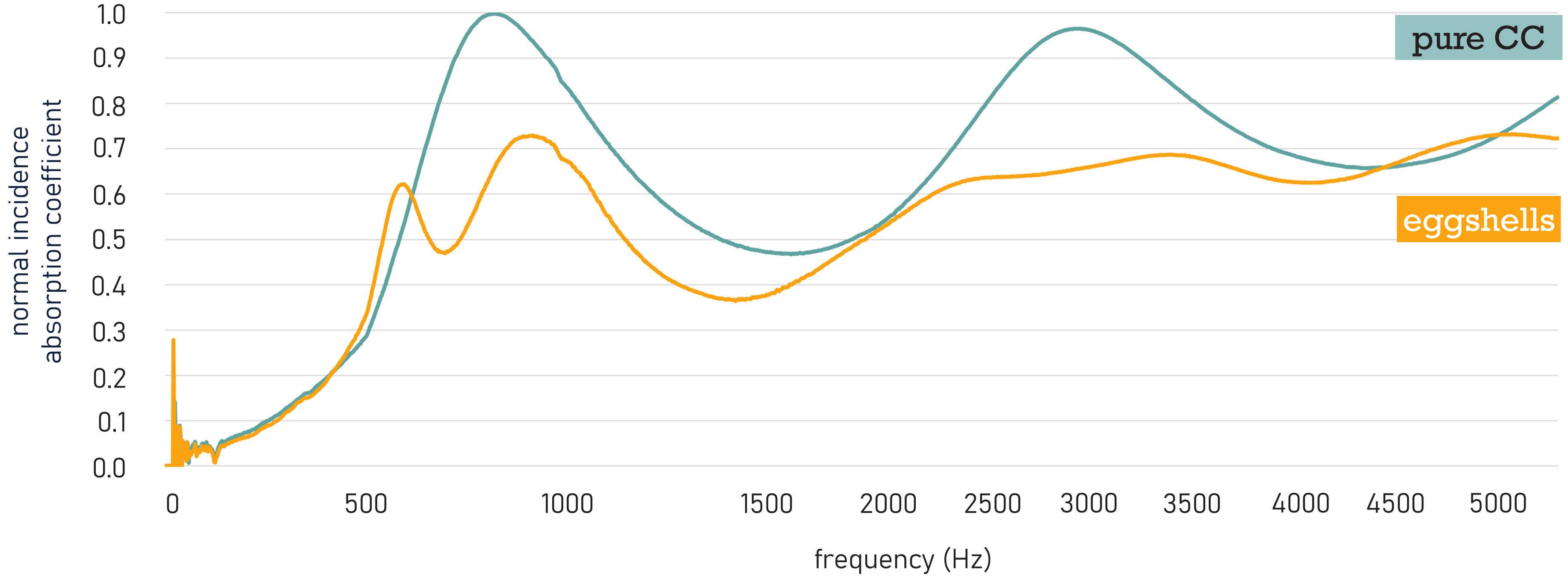
tortuosity



pure calcium carbonate

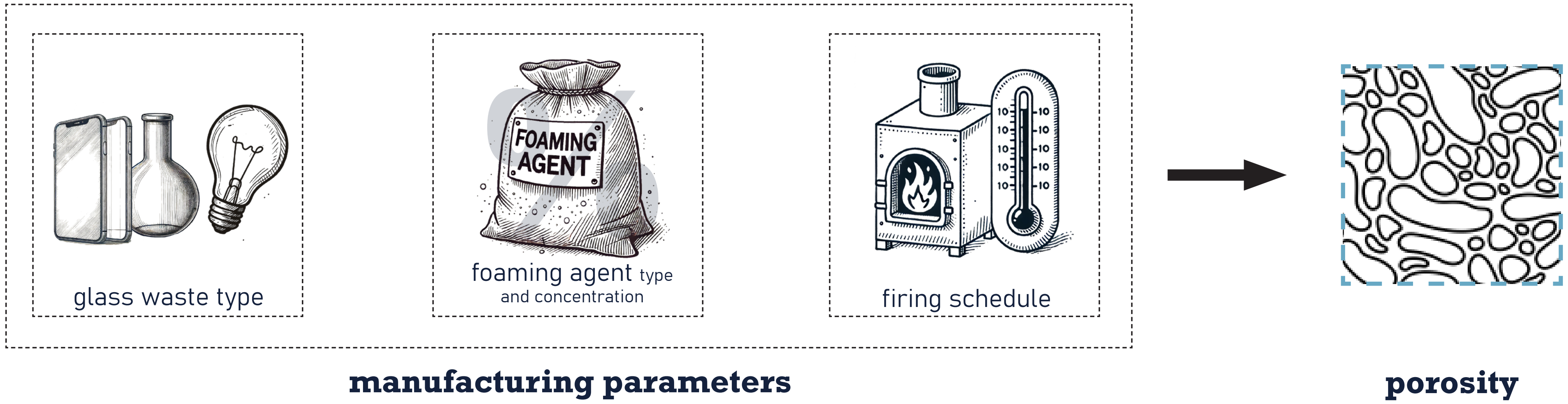
eggshells

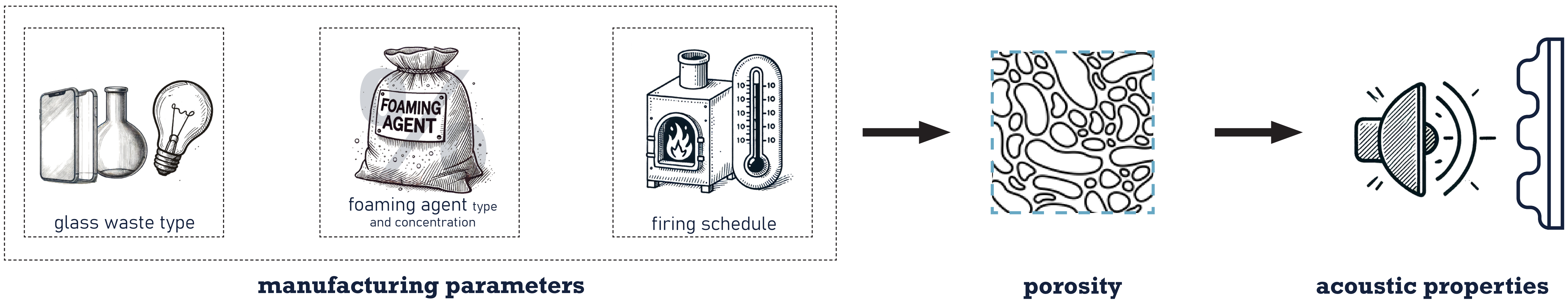
2.5 wt % foaming agent



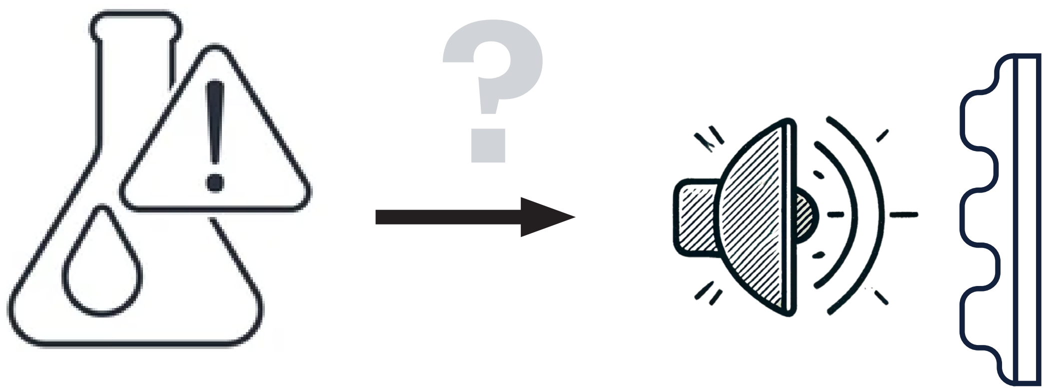
5 wt % foaming agent

manufacturing parameters


FOAMING AGENT
glass waste type
foaming agent type
and concentration
firing schedule
manufacturing parameters
porosity


glass waste type
FOAMING AGENT
foaming agent type
and concentration
firing schedule
manufacturing parameters
porosity
acoustic properties

What are the effects of **impurities** on the panel's acoustic properties?



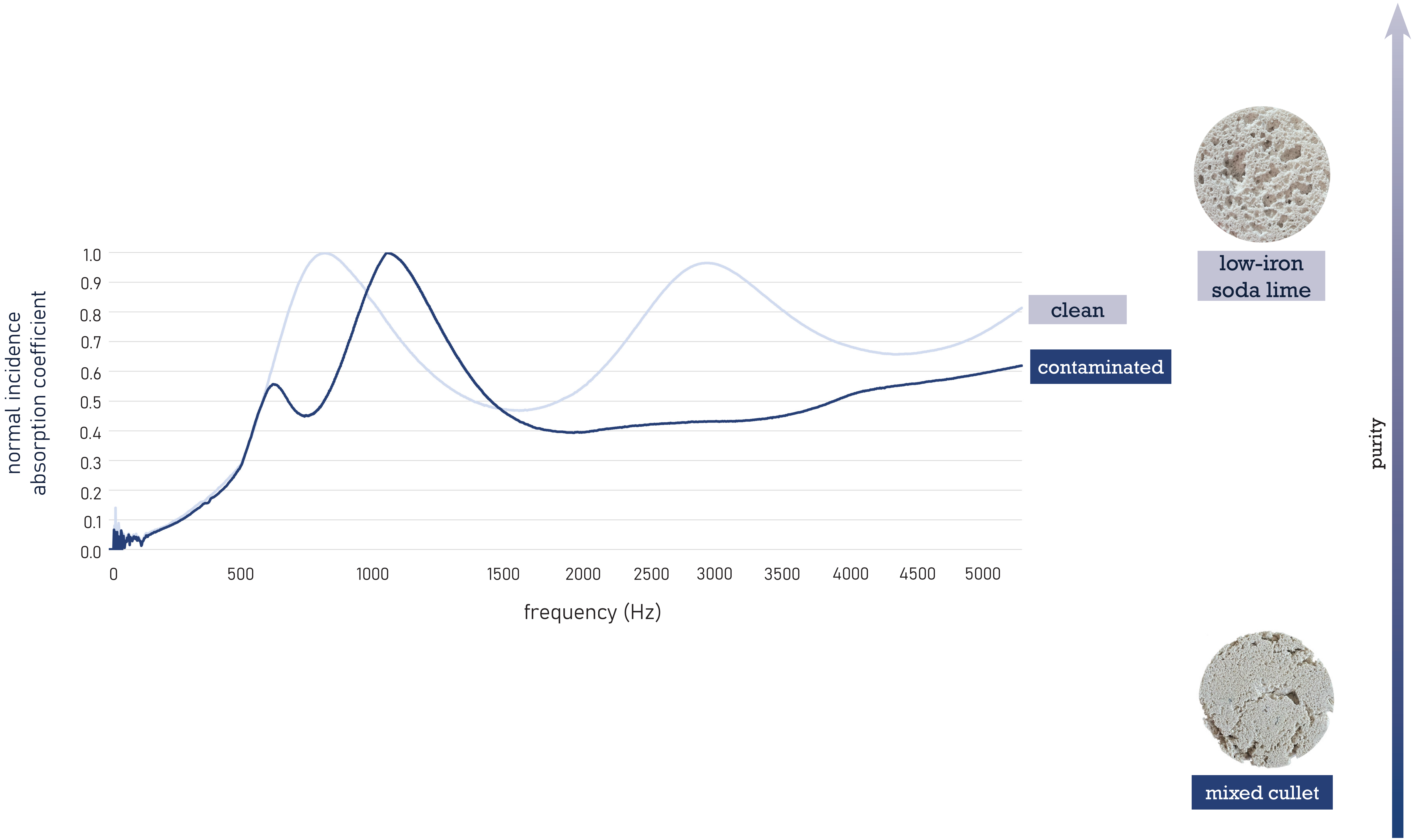
What are the effects of **impurities** on the panel's acoustic properties?

SODA LIME

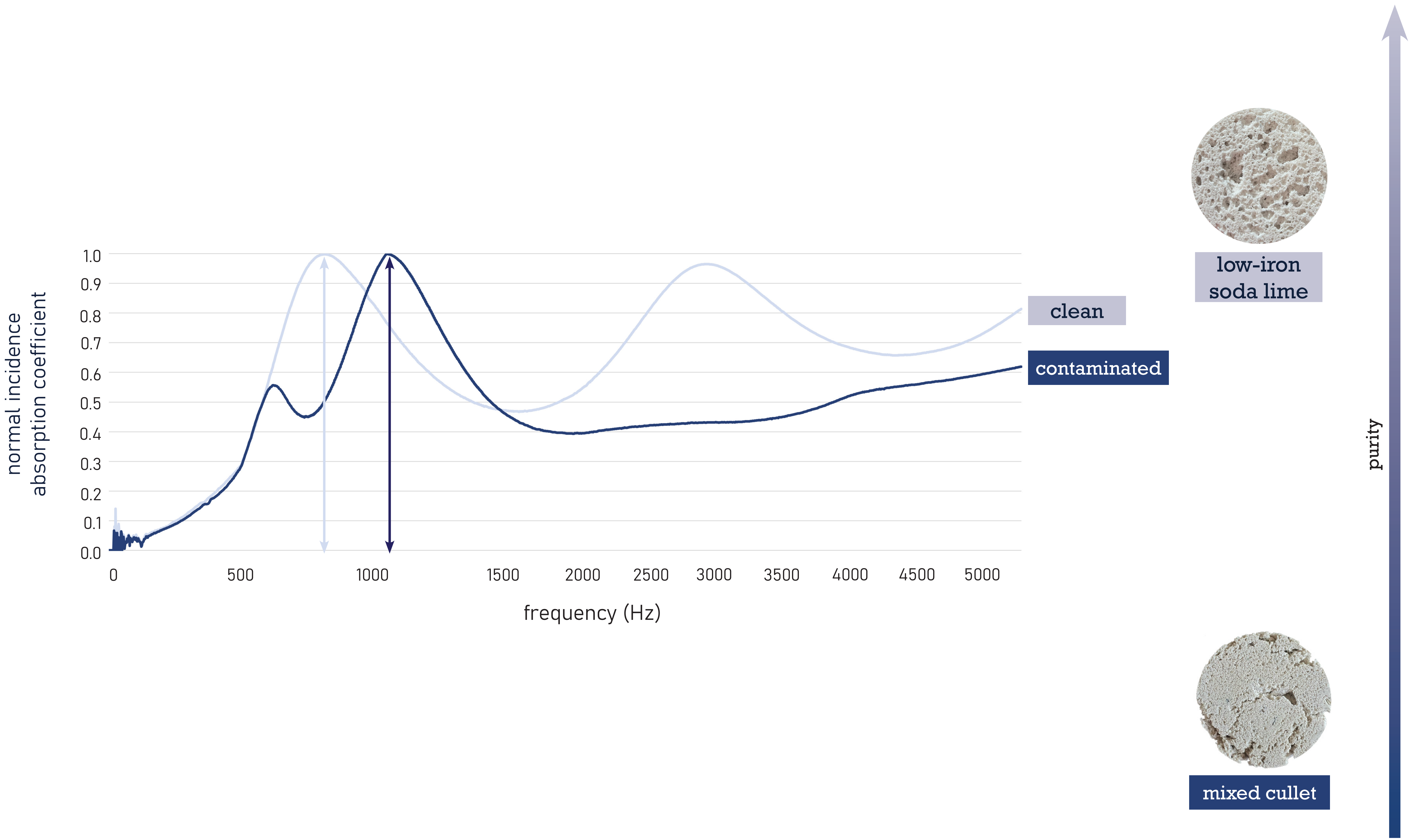
What are the effects of **impurities** on the panel's acoustic properties?

SODA LIME

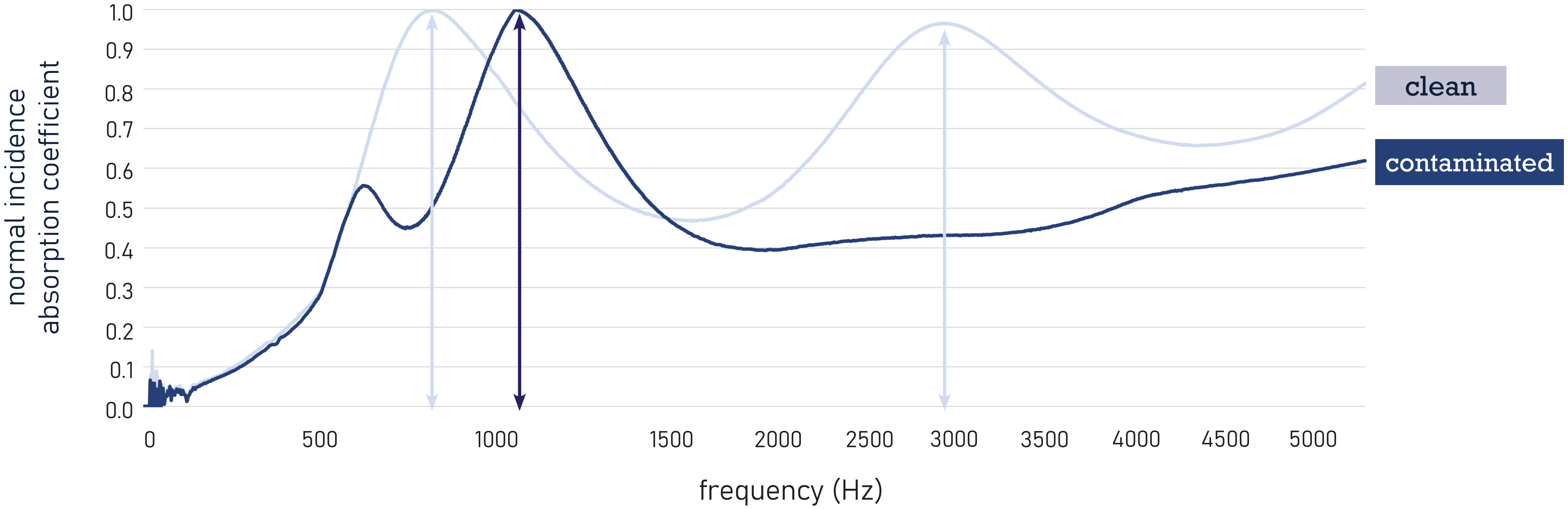
What are the effects of **impurities** on the panel's acoustic properties?

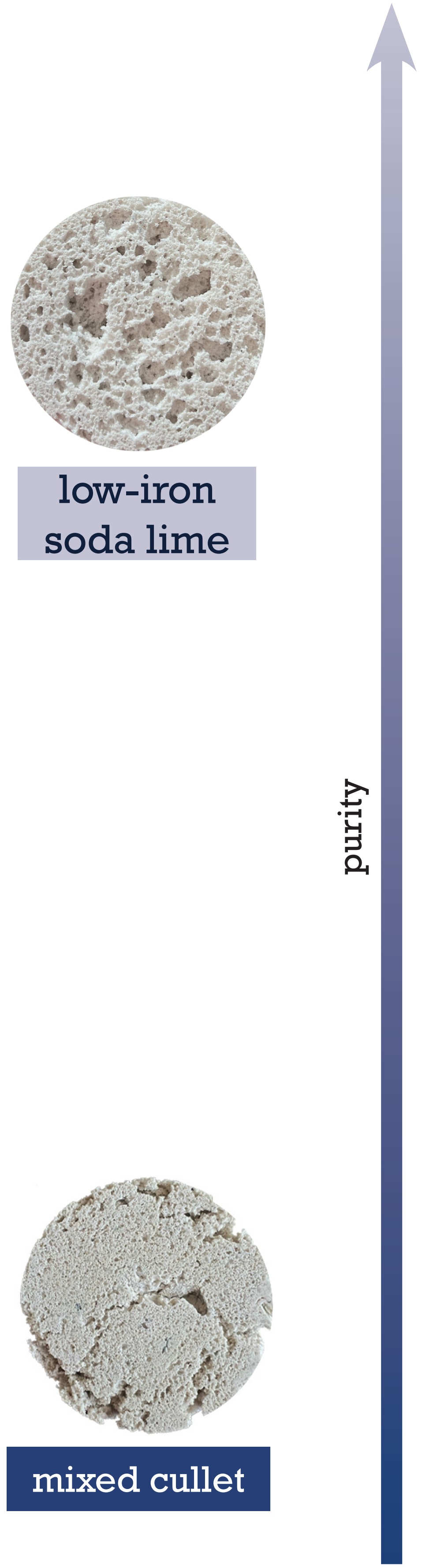


What are the effects of **impurities** on the panel's acoustic properties?

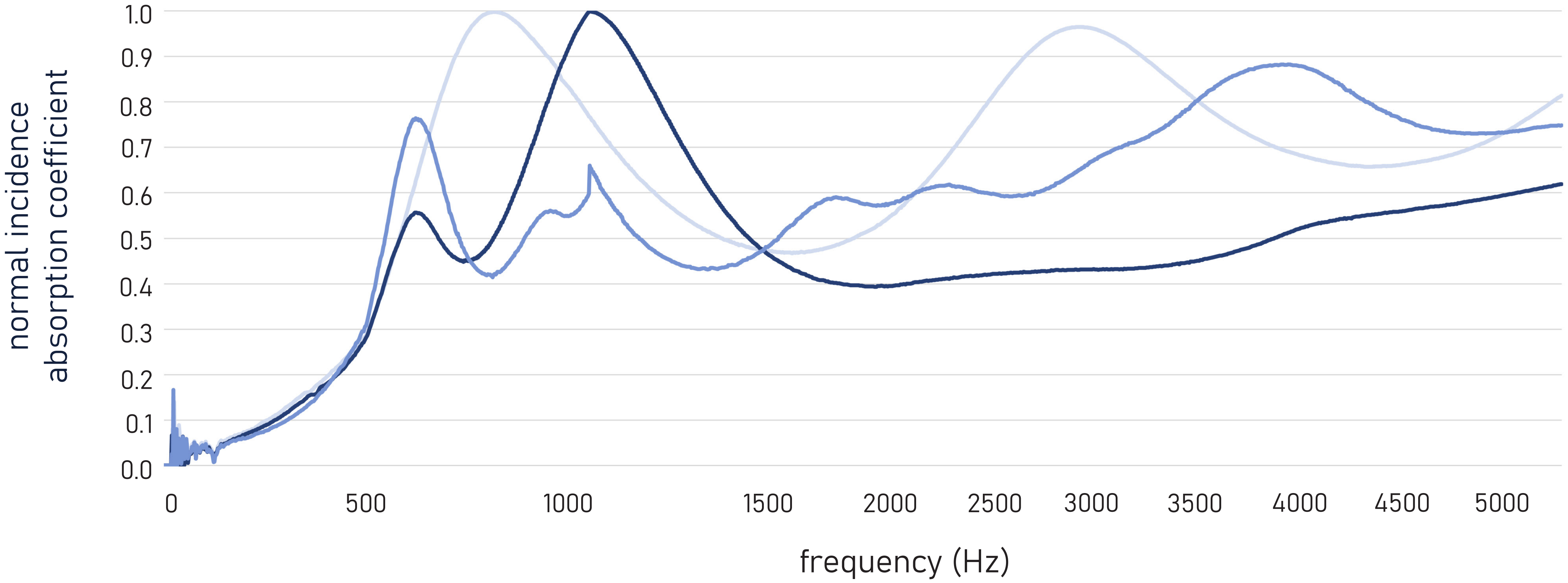


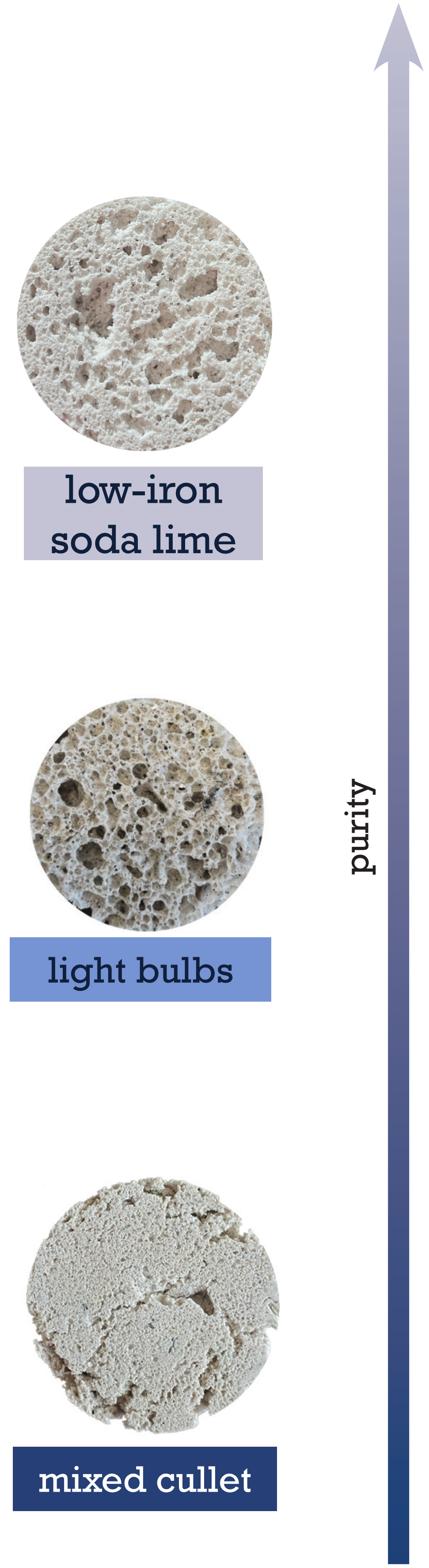
What are the effects of **impurities** on the panel's acoustic properties?



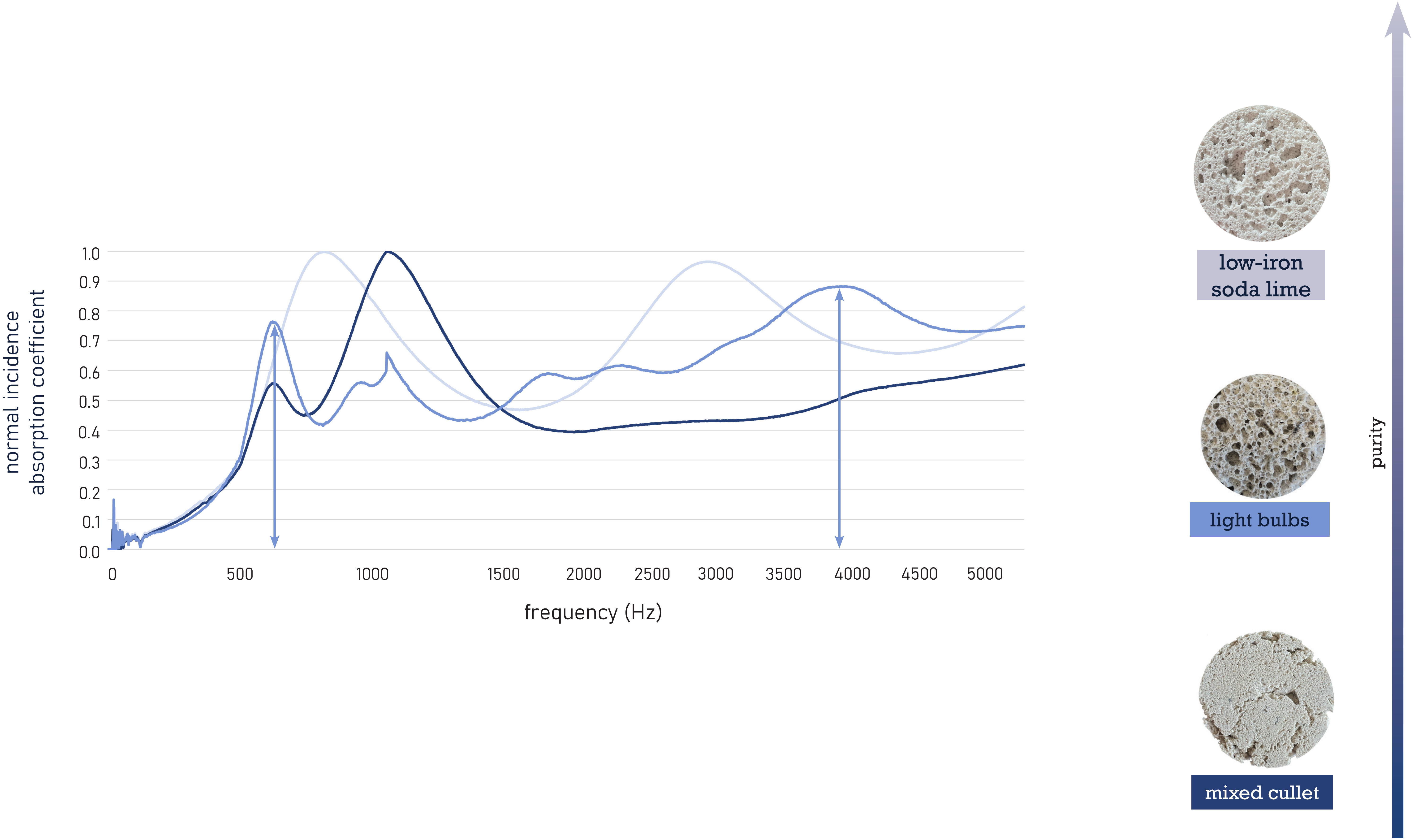


What are the effects of **impurities** on the panel's acoustic properties?





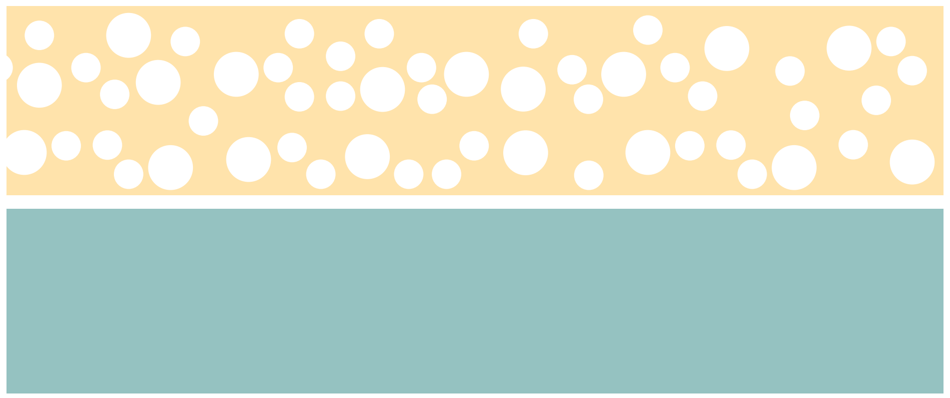
What are the effects of **impurities** on the panel's acoustic properties?



safety

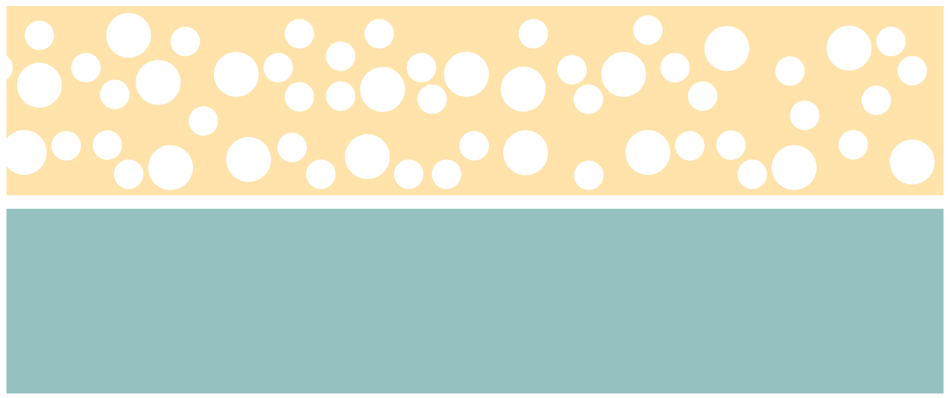
safety

safety

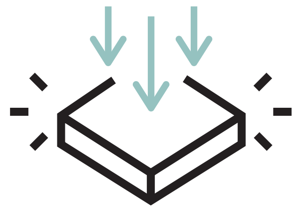


tack fusing

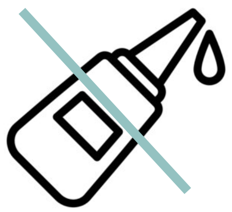
safety



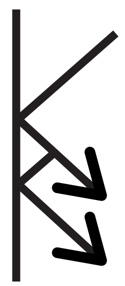
tack fusing



rigidity

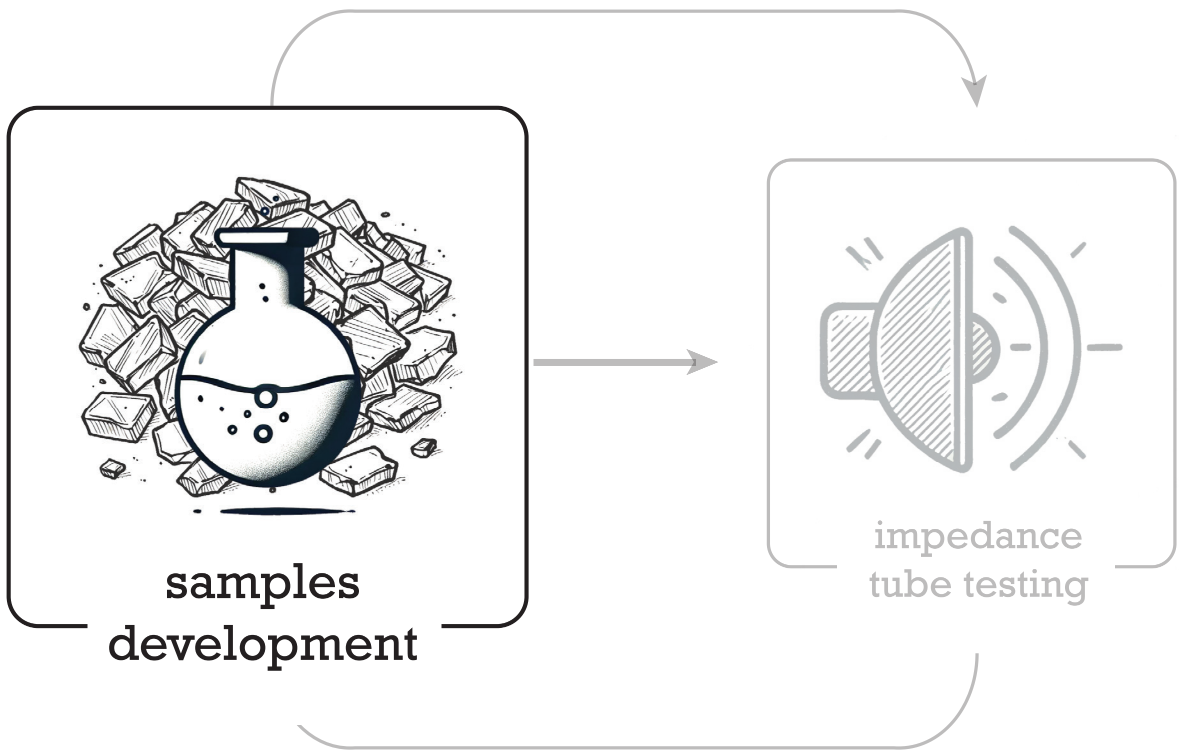


adhesive - free bonding



acoustic reflector

safety



fusing

2 - step: tack fusing

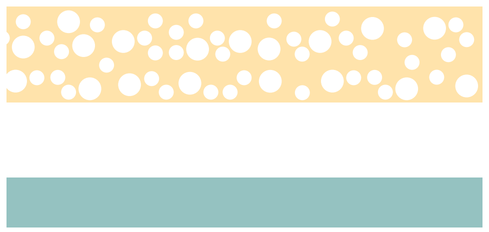
step 1: foaming

pre-foamed

fusing

2 – step: tack fusing

step 1: foaming



fusing

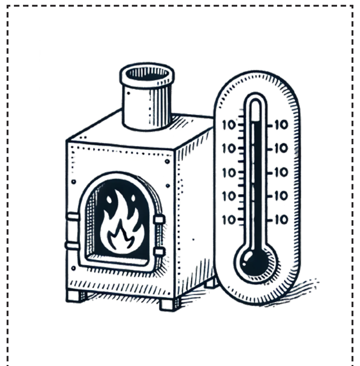
2 – step: tack fusing

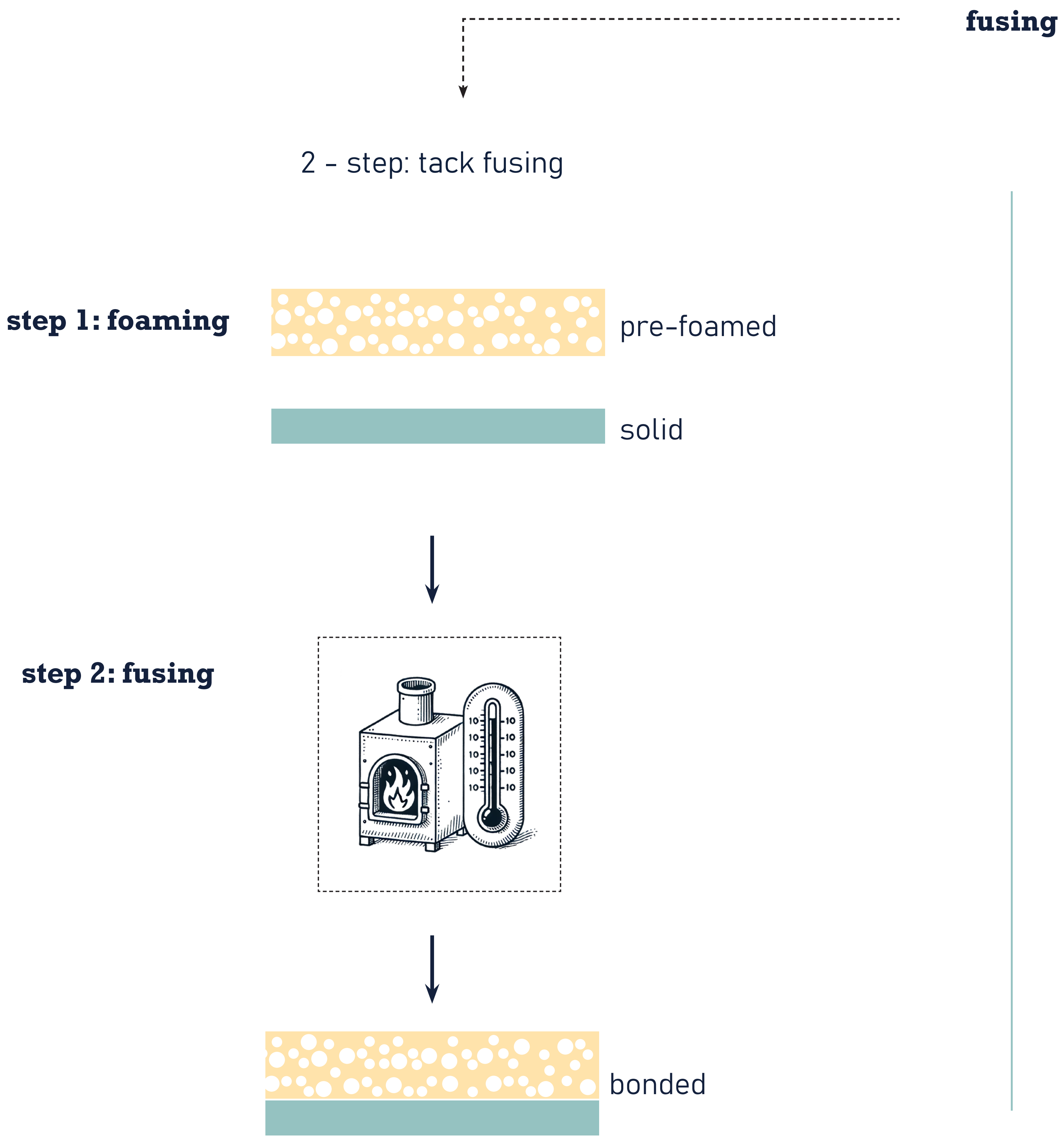
step 1: foaming

pre-foamed

solid

step 2: fusing

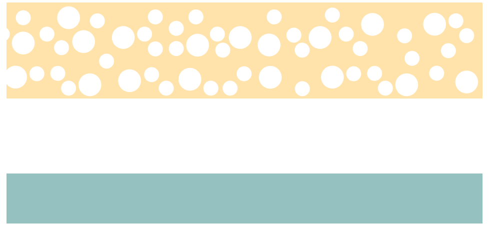



fusing
2 - step: tack fusing
step 1: foaming
pre-foamed
solid
step 2: fusing
bonded

fusing

2 - step: tack fusing

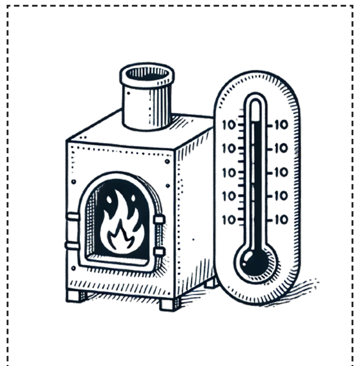
step 1: foaming

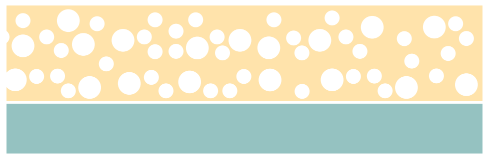


pre-foamed

solid

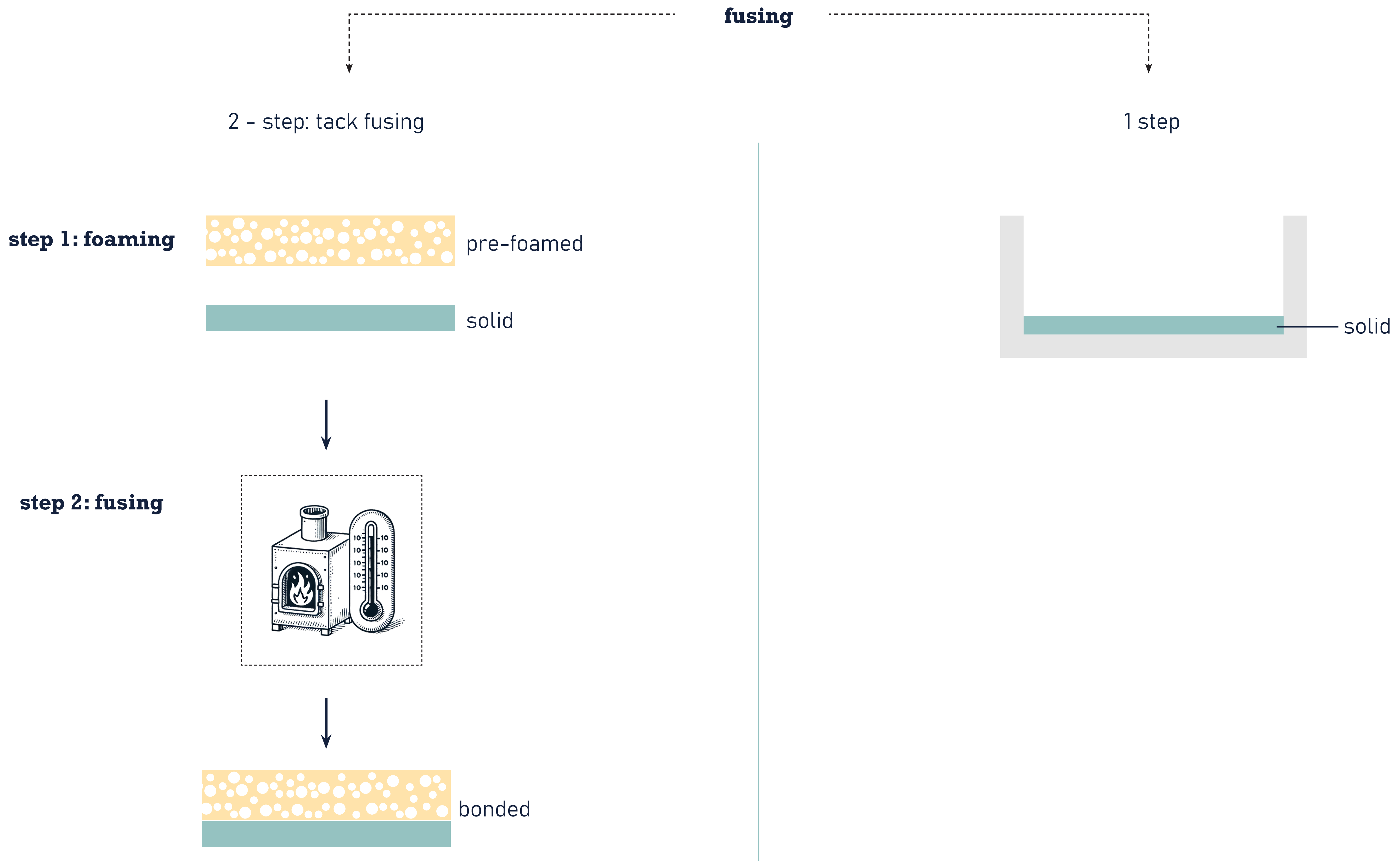
step 2: fusing





bonded

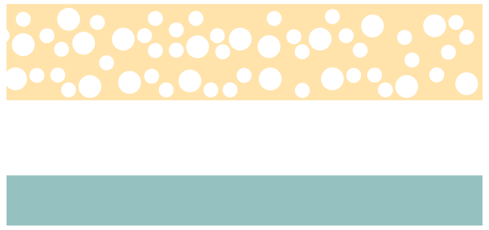
1 step


fusing
2 - step: tack fusing
1 step
step 1: foaming
pre-foamed
solid
solid
step 2: fusing
bonded

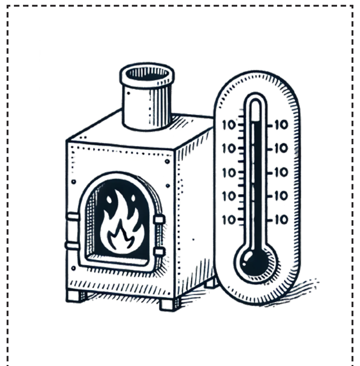
fusing

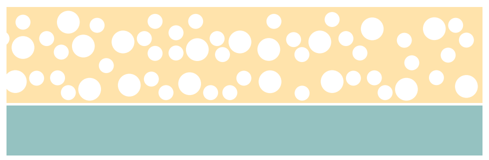
2 - step: tack fusing

step 1: foaming

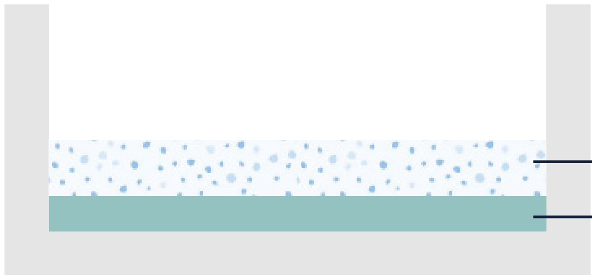


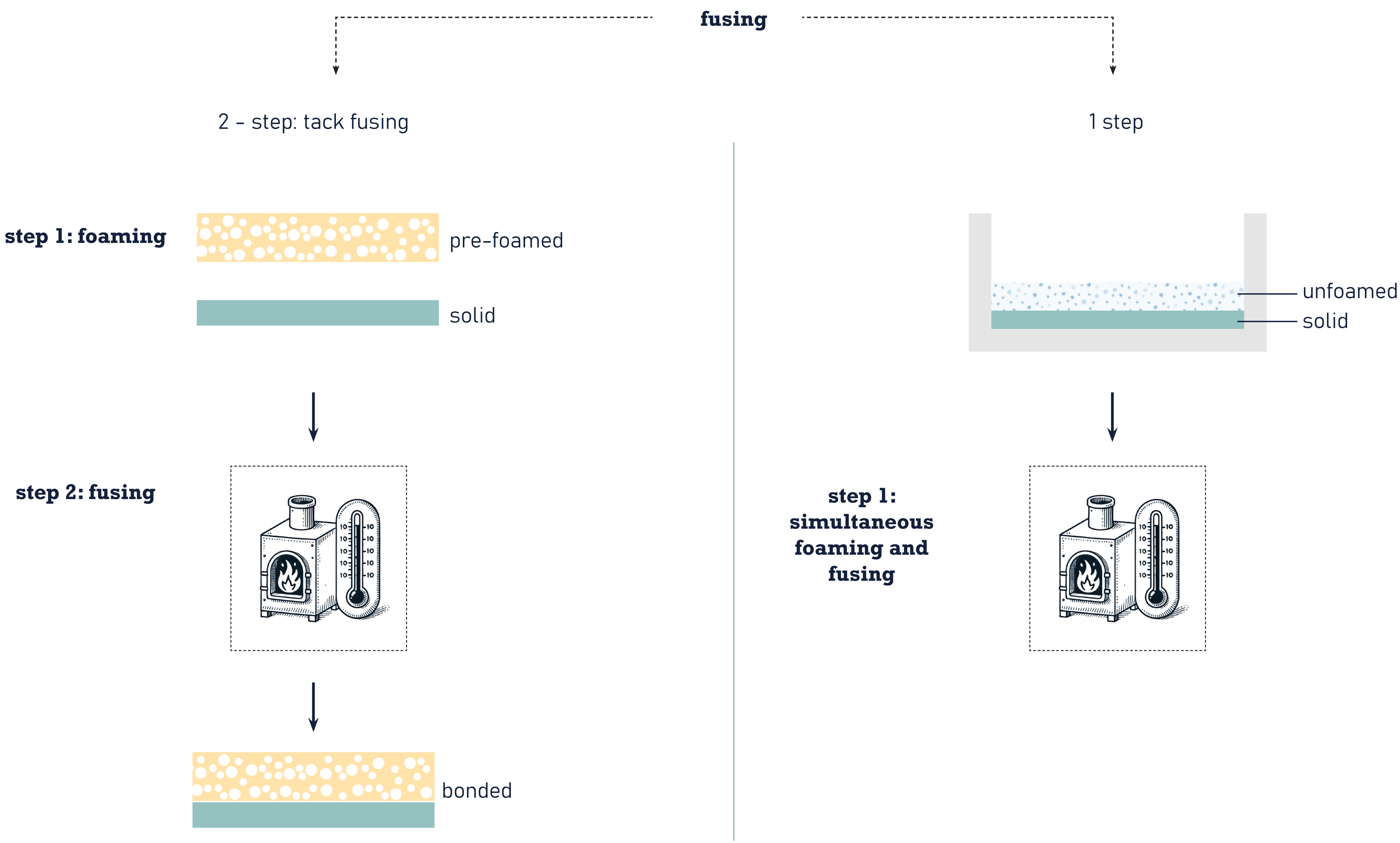
step 2: fusing

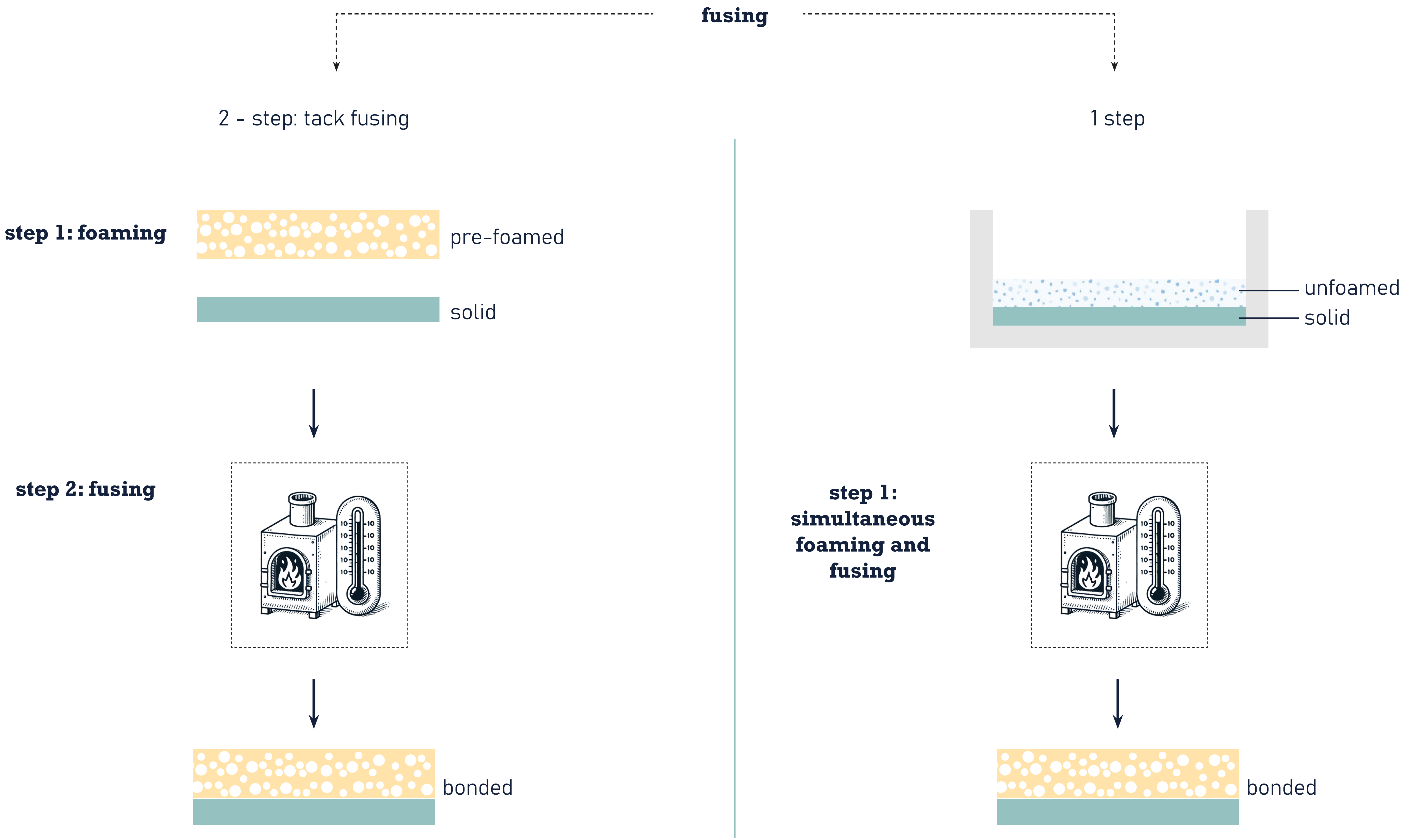




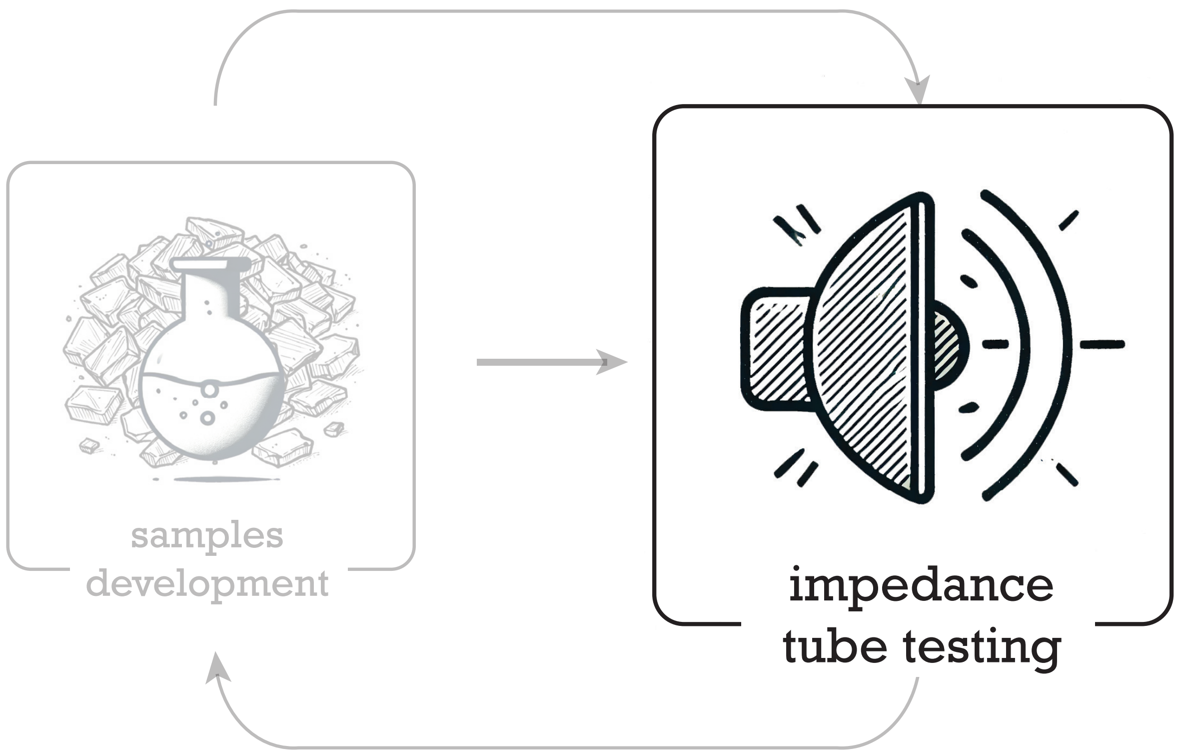
1 step

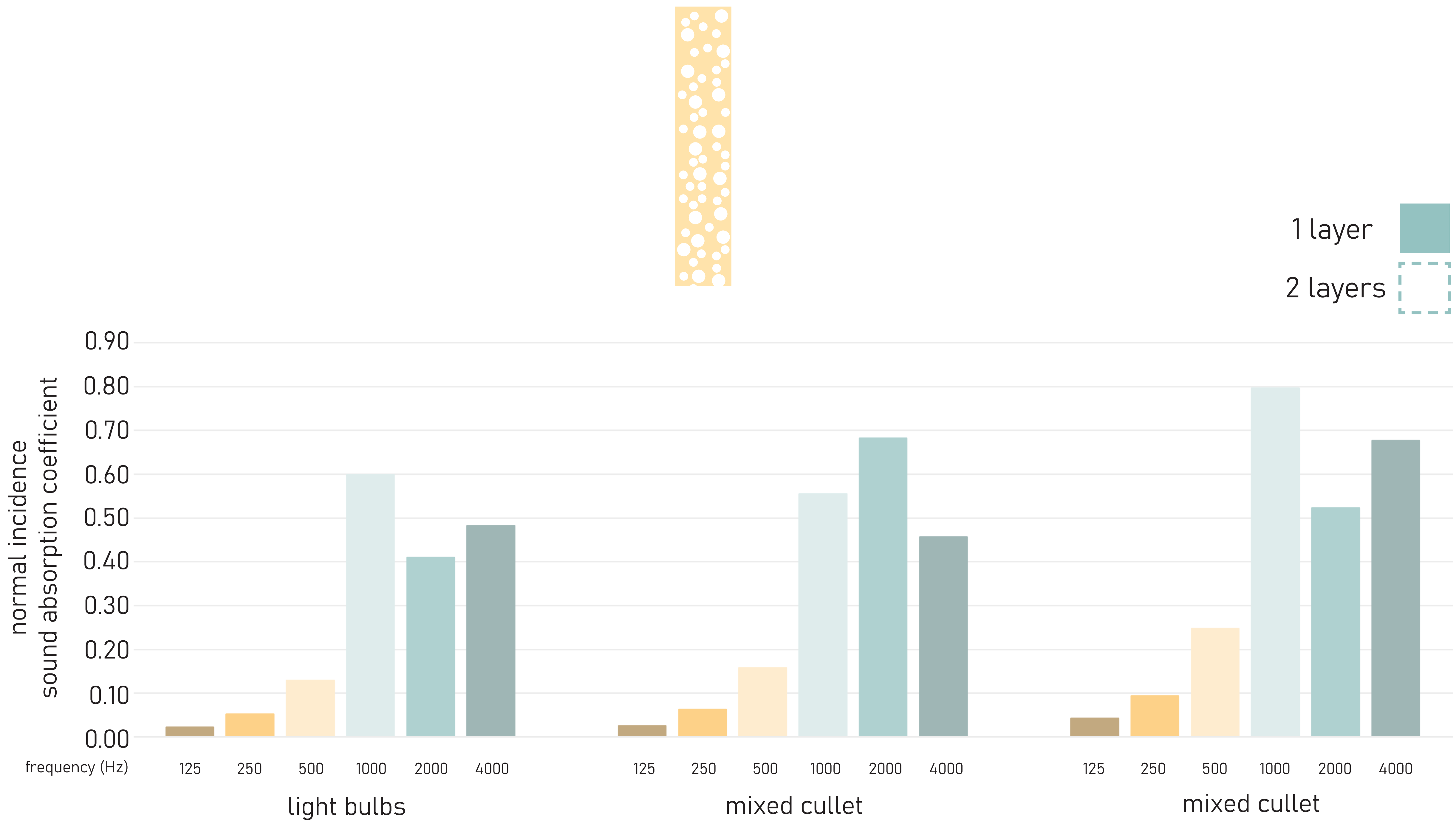


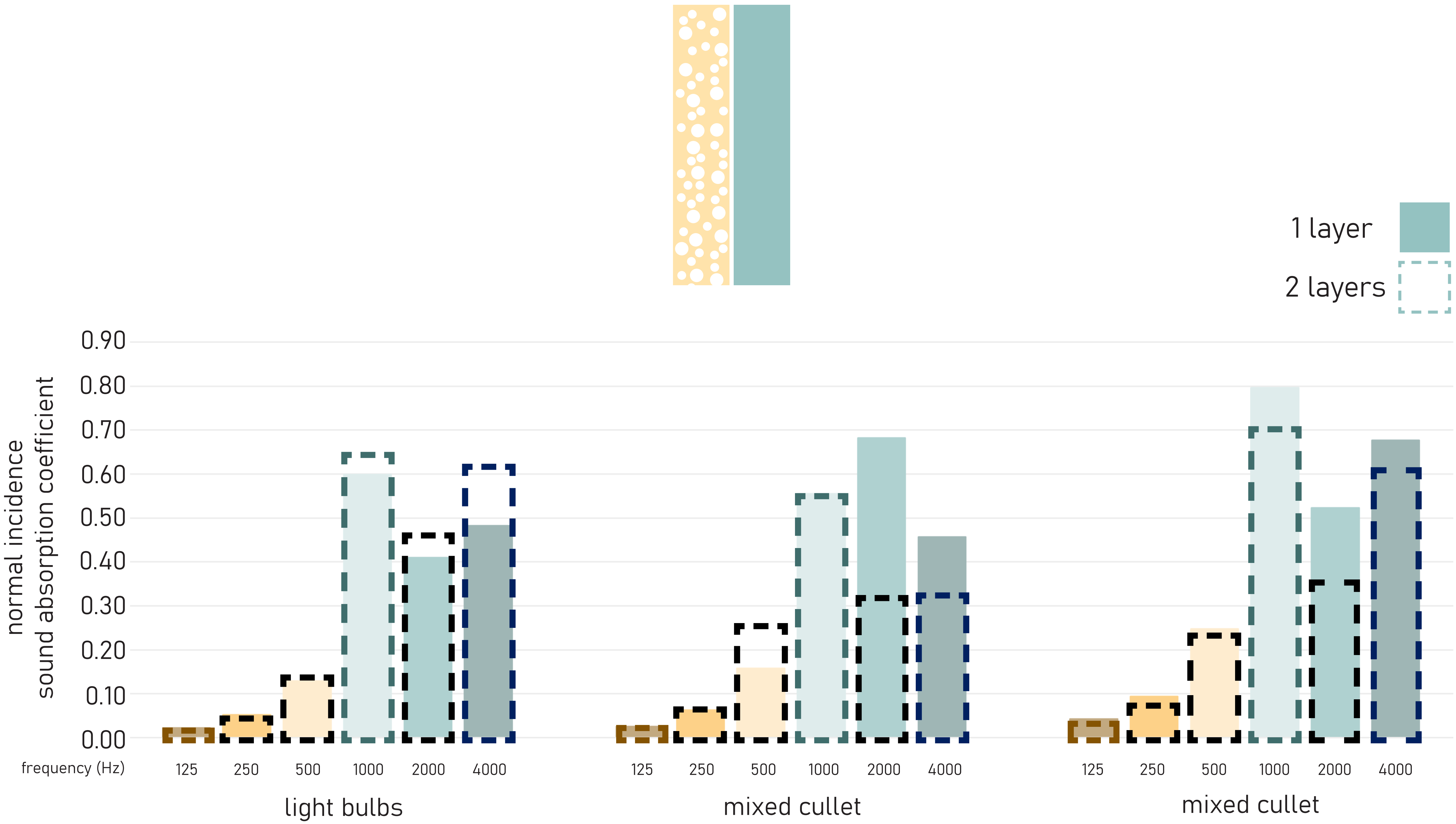

fusing
2 - step: tack fusing
1 step
step 1: foaming
pre-foamed
solid
unfoamed
solid
step 2: fusing
step 1: simultaneous foaming and fusing
bonded

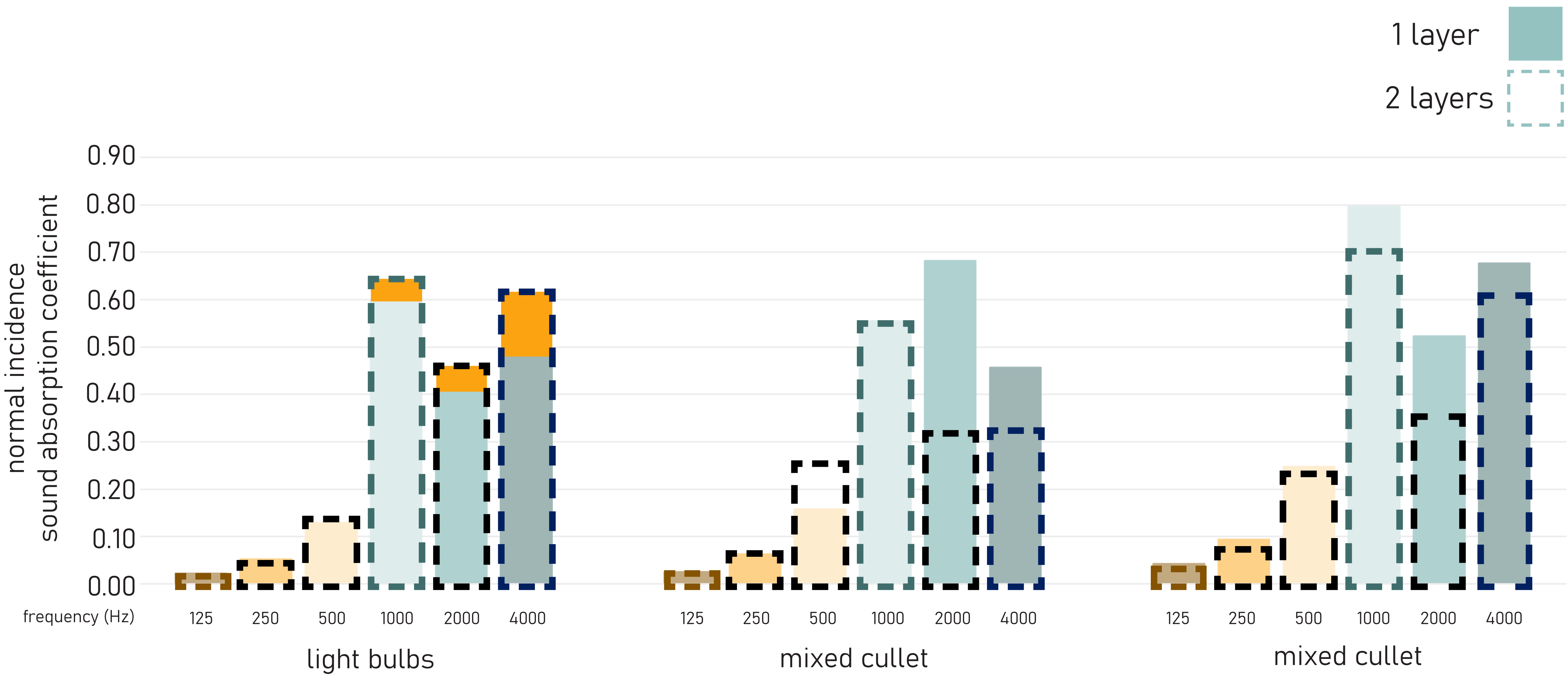


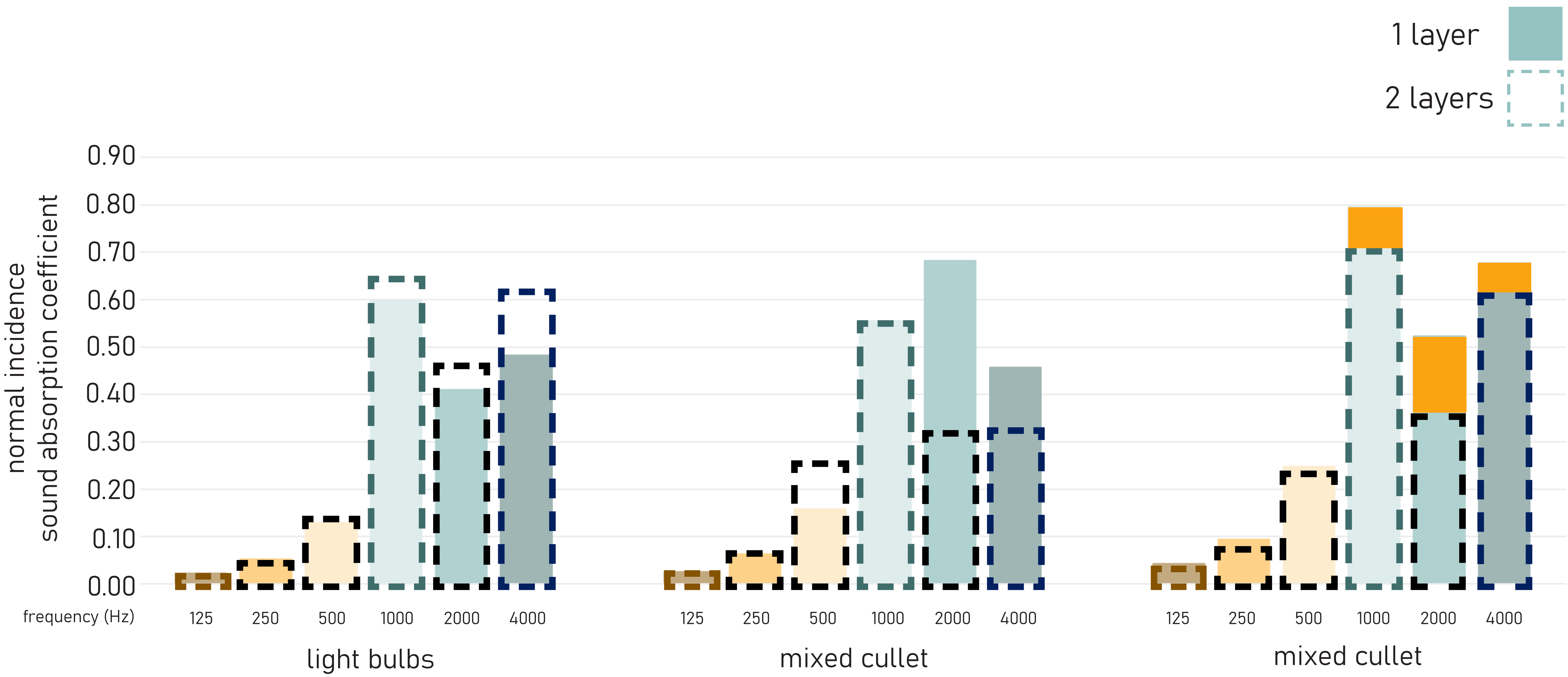
fusing
2 - step: tack fusing
1 step
step 1: foaming
pre-foamed
solid
unfoamed
solid
step 2: fusing
step 1: simultaneous foaming and fusing
bonded
bonded


samples
development
impedance
tube testing


1 layer
2 layers
normal incidence
sound absorption coefficient
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
frequency (Hz)
125
250
500
1000
2000
4000
light bulbs
125
250
500
1000
2000
4000
mixed cullet
125
250
500
1000
2000
4000
mixed cullet

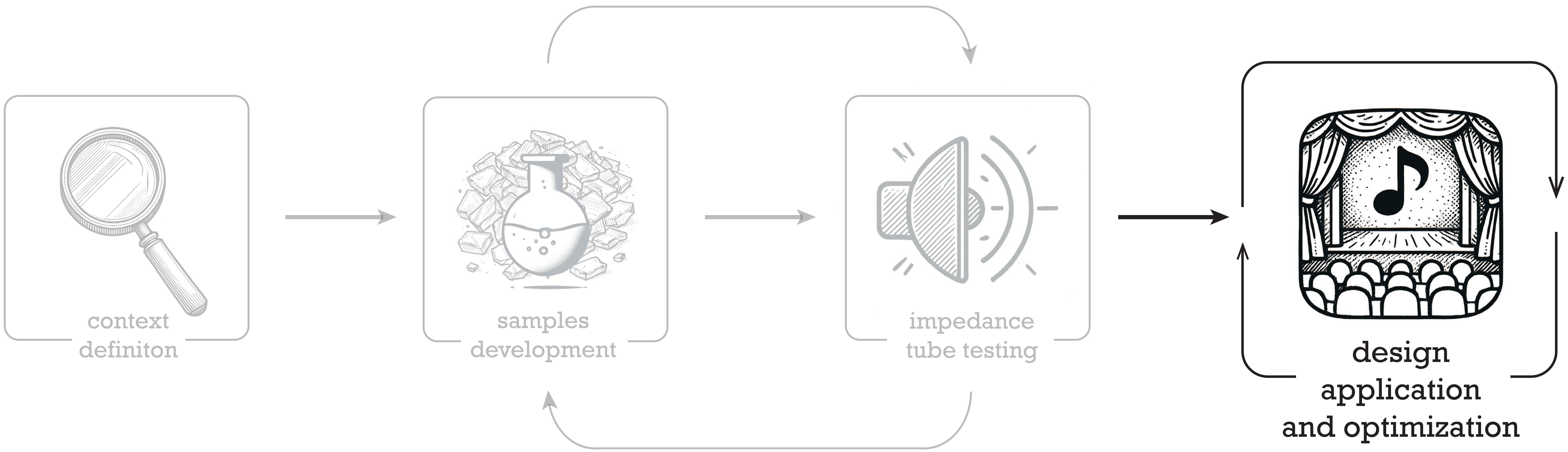

1 layer
2 layers
normal incidence
sound absorption coefficient
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
frequency (Hz)
125
250
500
1000
2000
4000
light bulbs
mixed cullet
mixed cullet


1 layer
2 layers
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
normal incidence
sound absorption coefficient
frequency (Hz)
125
250
500
1000
2000
4000
light bulbs
mixed cullet
mixed cullet

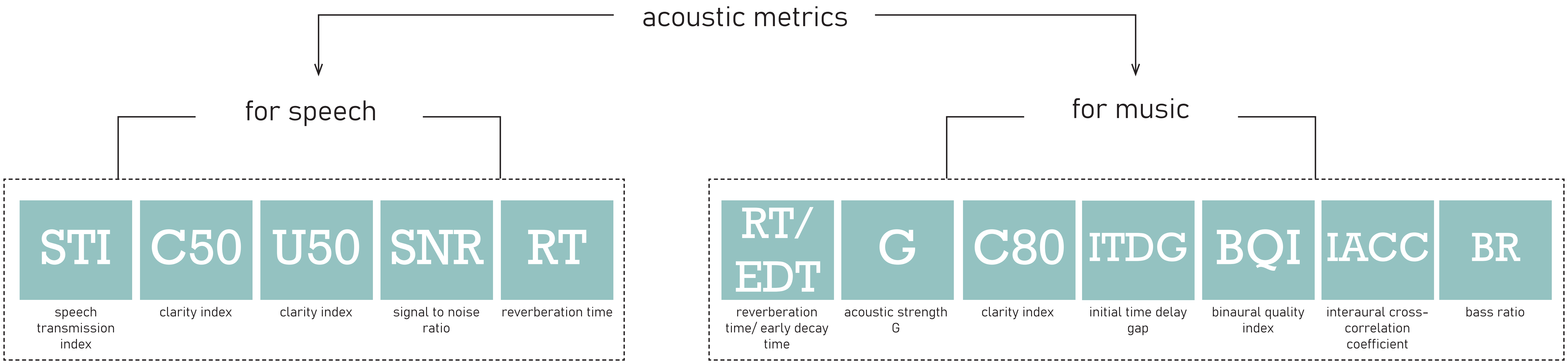

1 layer
2 layers
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
normal incidence
sound absorption coefficient
frequency (Hz)
125
250
500
1000
2000
4000
light bulbs
125
250
500
1000
2000
4000
mixed cullet
125
250
500
1000
2000
4000
mixed cullet

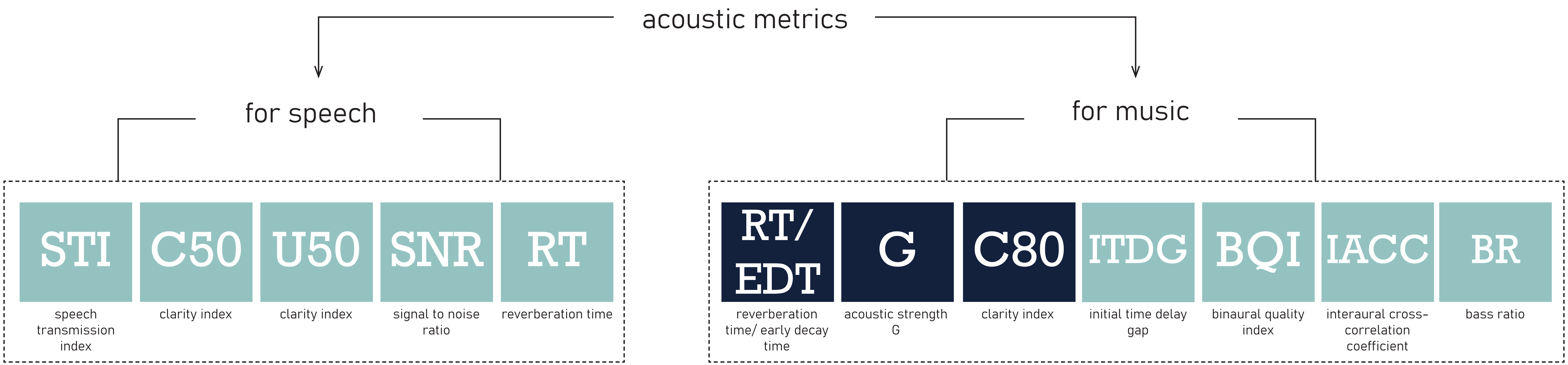
application

context definition — **experimental research** — **design application**



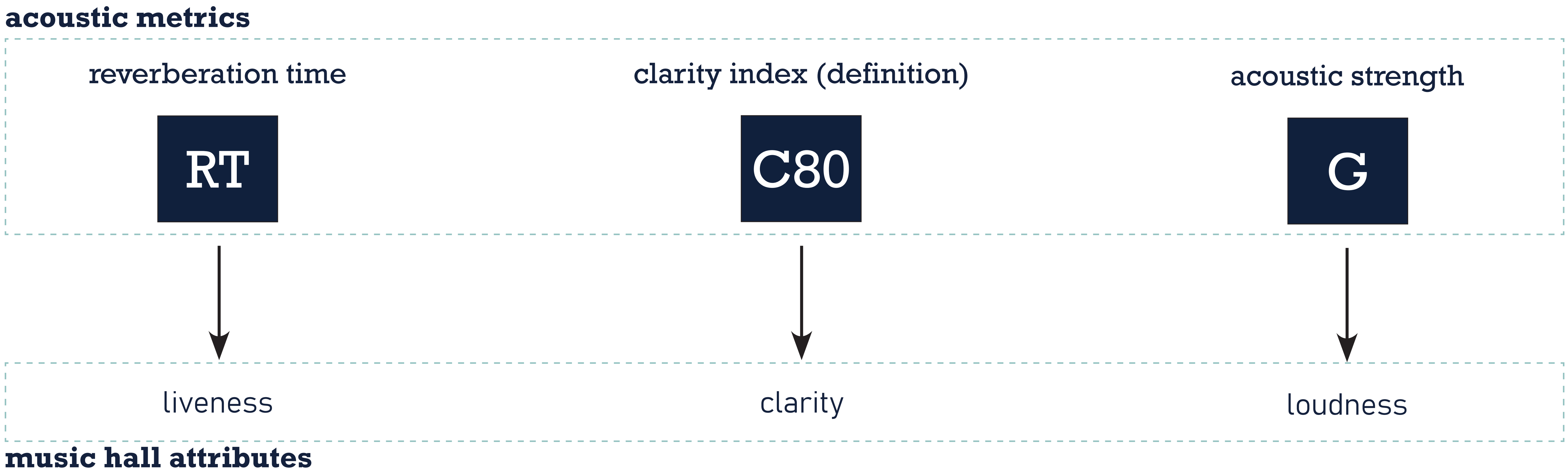
Theatre Hall, TU Delft X


acoustic metrics
for speech
STI
speech transmission index
C50
clarity index
U50
clarity index
SNR
signal to noise ratio
RT
reverberation time
for music
RT/ EDT
reverberation time/ early decay time
G
acoustic strength G
C80
clarity index
ITDG
initial time delay gap
BQI
binaural quality index
IACC
interaural cross-correlation coefficient
BR
bass ratio


acoustic metrics
for speech
for music
STI
speech transmission index
C50
clarity index
U50
clarity index
SNR
signal to noise ratio
RT
reverberation time
RT/ EDT
reverberation time/ early decay time
G
acoustic strength G
C80
clarity index
ITDG
initial time delay gap
BQI
binaural quality index
IACC
interaural cross-correlation coefficient
BR
bass ratio

acoustic metrics

reverberation time	clarity index (definition)	acoustic strength
RT	C80	G


acoustic metrics
reverberation time
RT
clarity index (definition)
C80
acoustic strength
G
liveness
clarity
loudness
music hall attributes

acoustic metrics

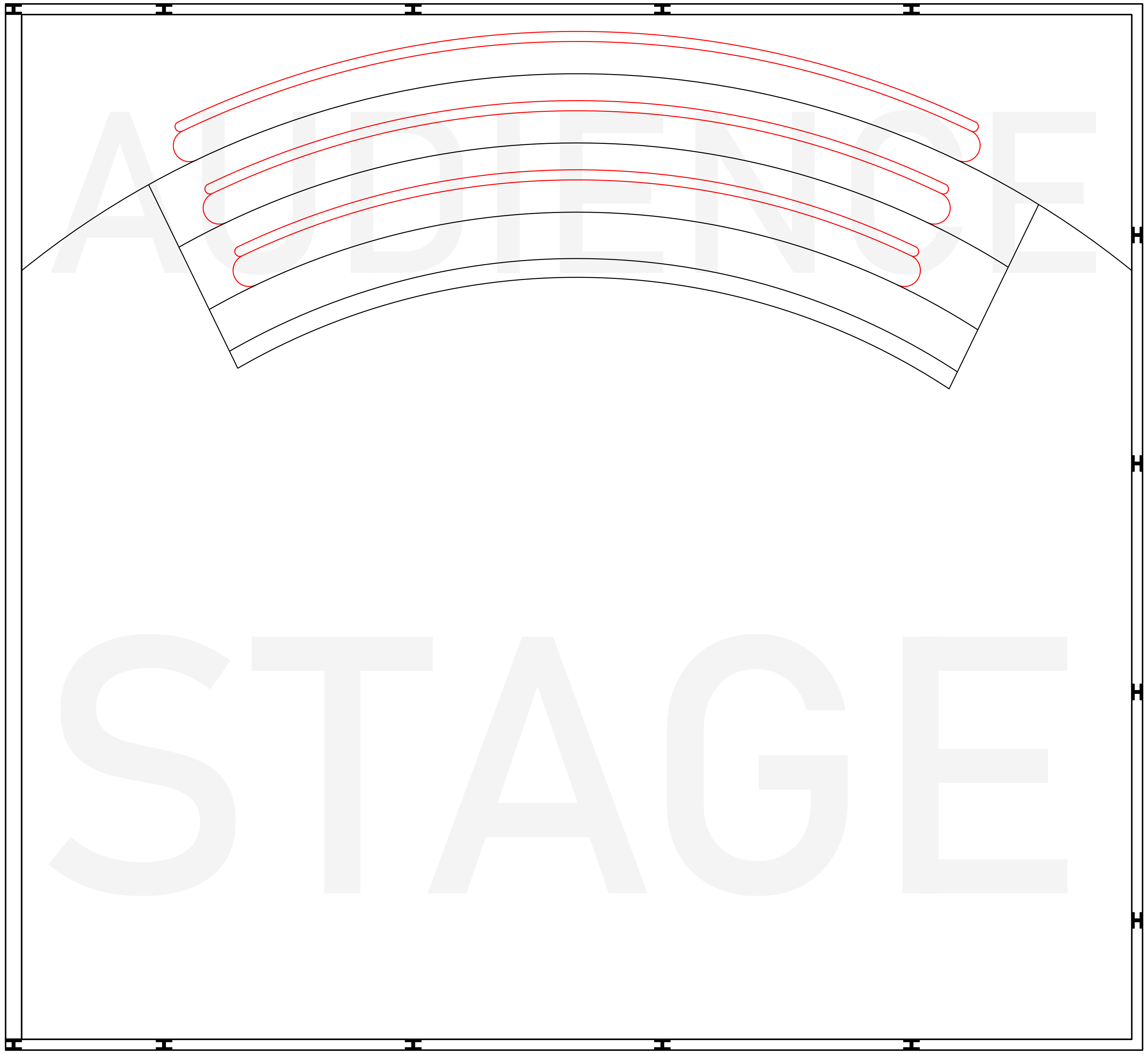
reverberation time	clarity index (definition)	acoustic strength
RT	C80	G
↓	↓	↓
liveness	clarity	loudness

music hall attributes

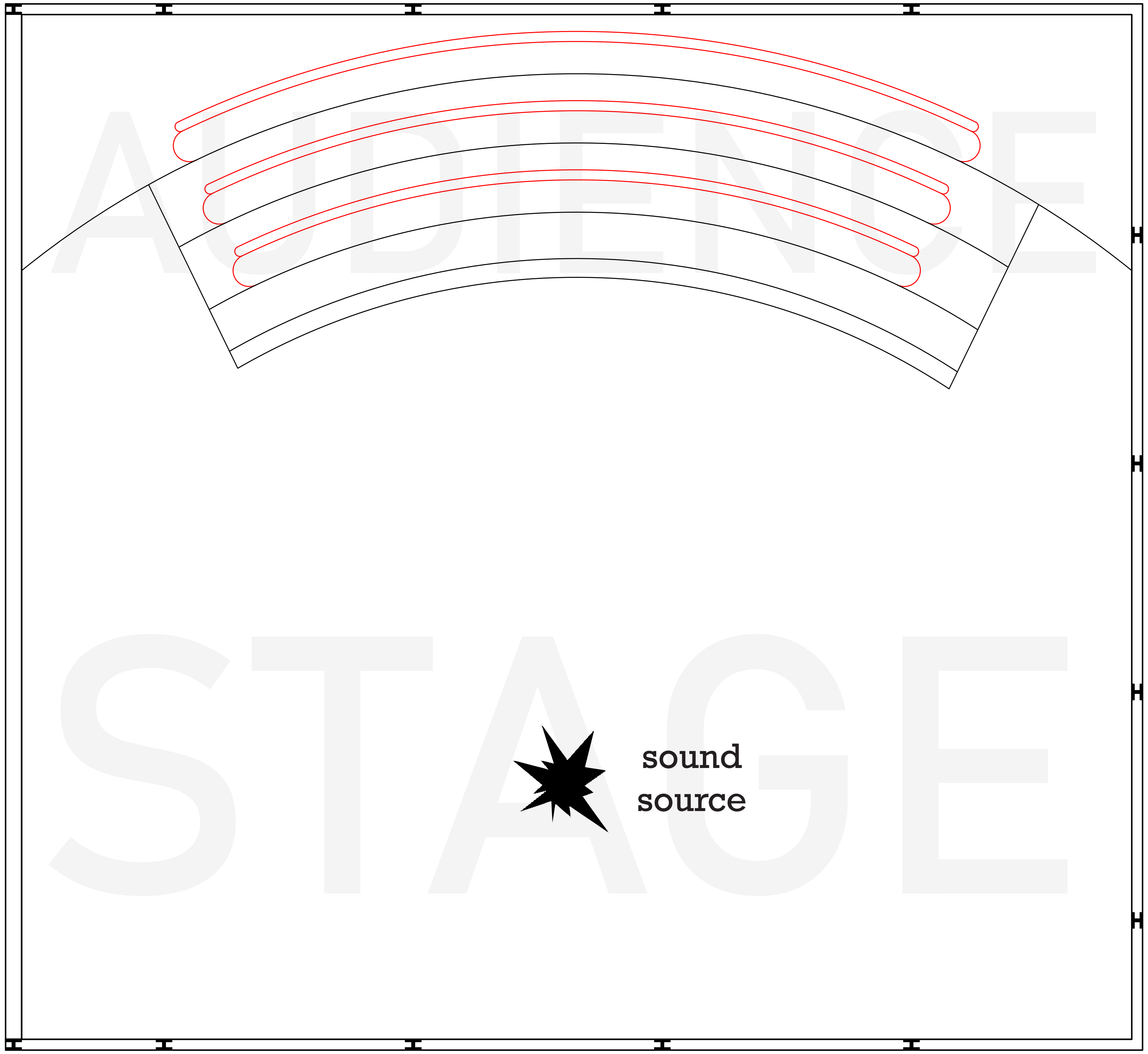
speaker

microphone

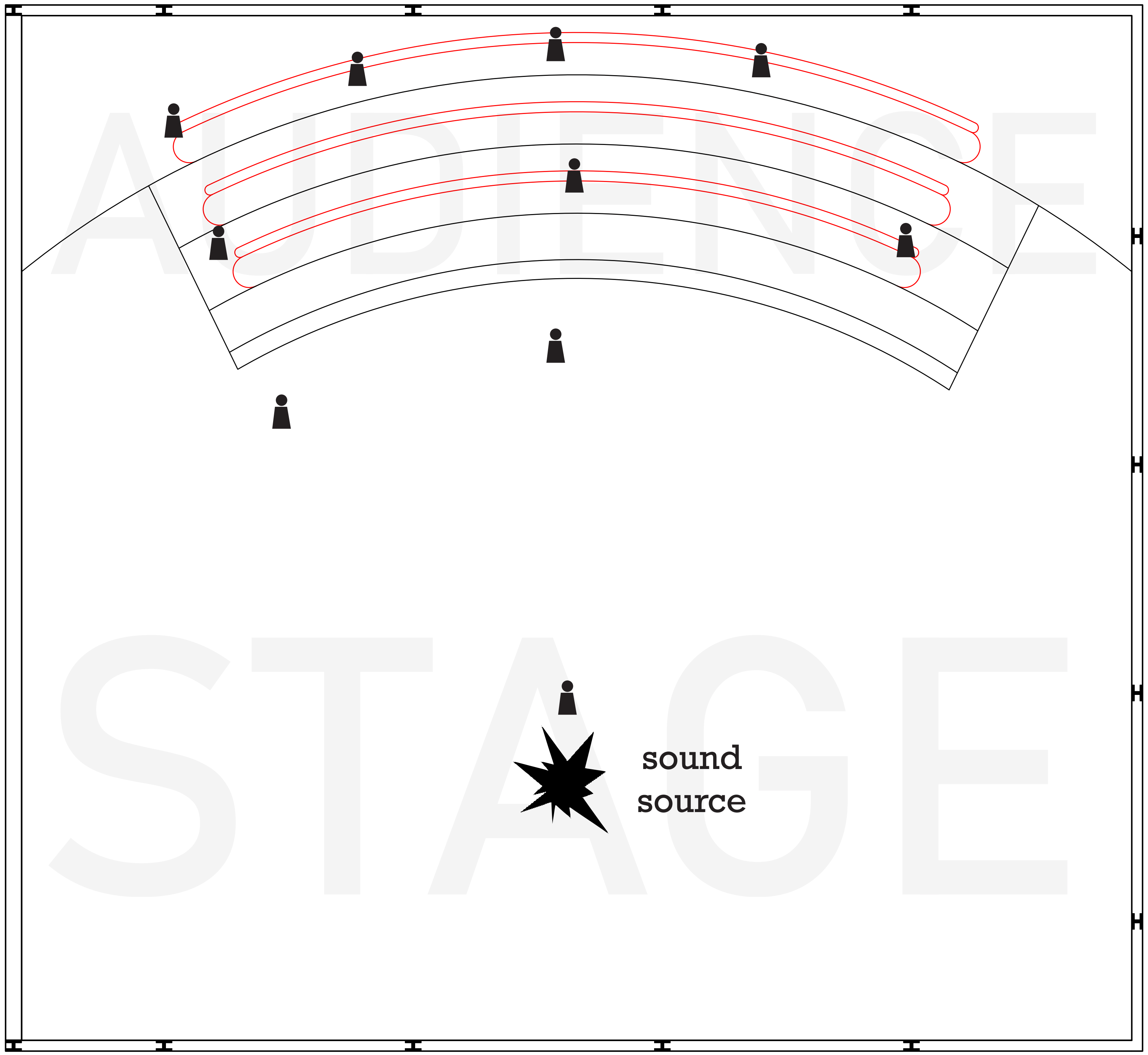
set up



Theatre Hall, top view



Theatre Hall, top view



Theatre Hall, top view

reverberation time

RT

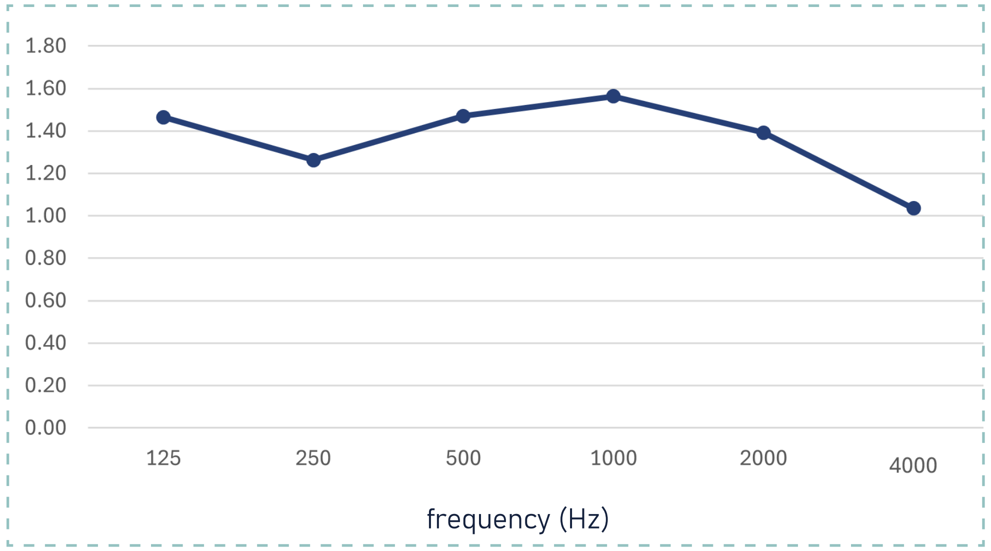
clarity index (definition)

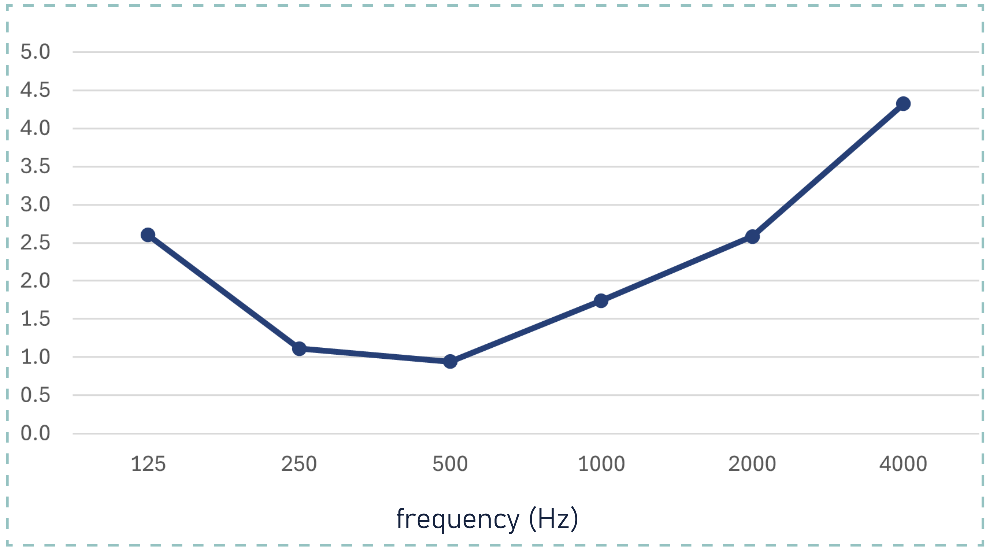
C80

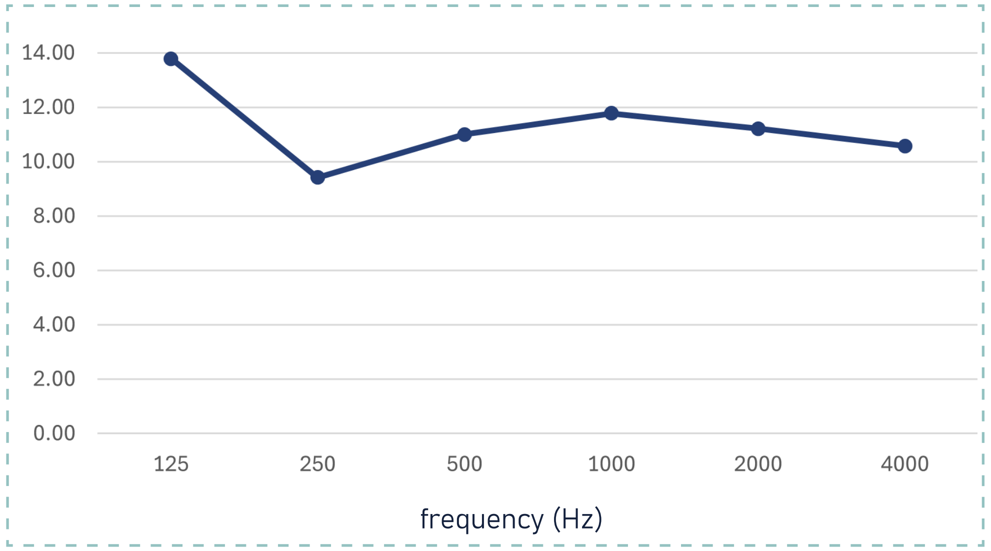
acoustic strength

G

measured values (unoccupied scenario)







reverberation time

RT

clarity index (definition)

C80

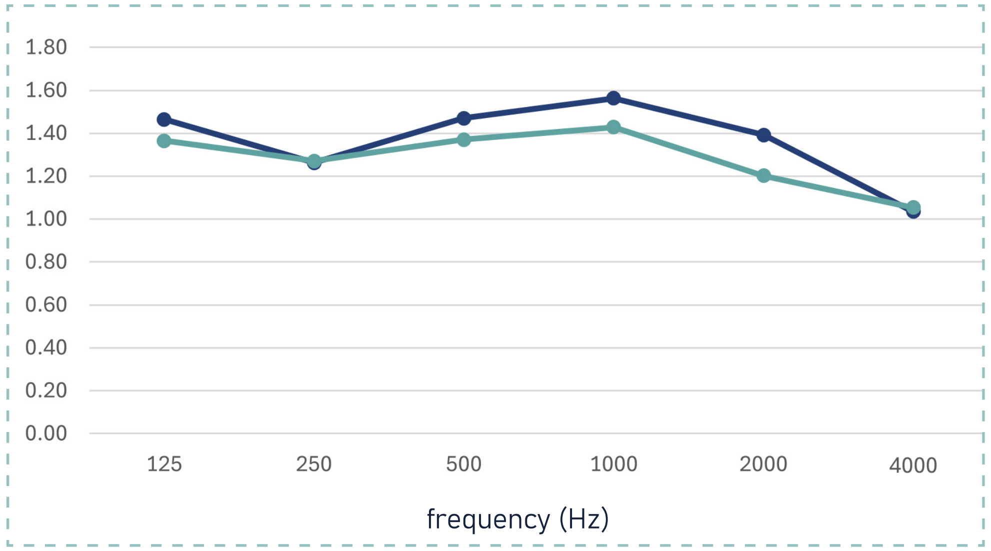
acoustic strength

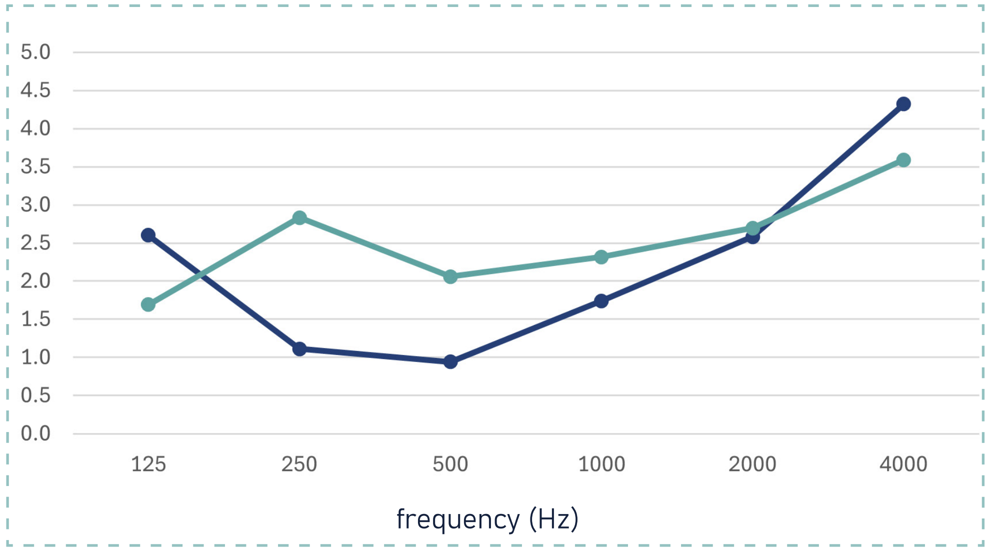
G

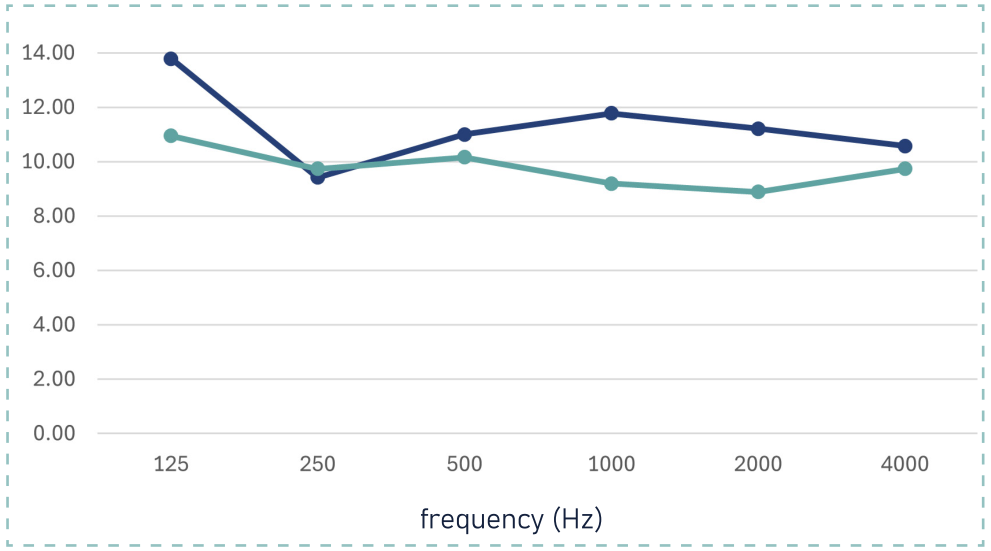
measured values (unoccupied scenario)

simulated values (occupied scenario)

VS.







reverberation time

RT

clarity index (definition)

C80

acoustic strength

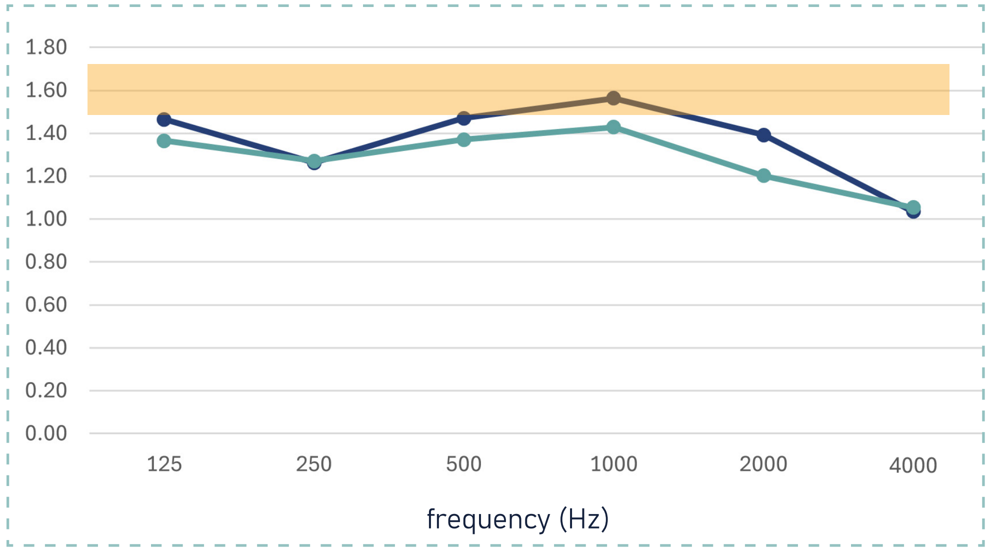
G

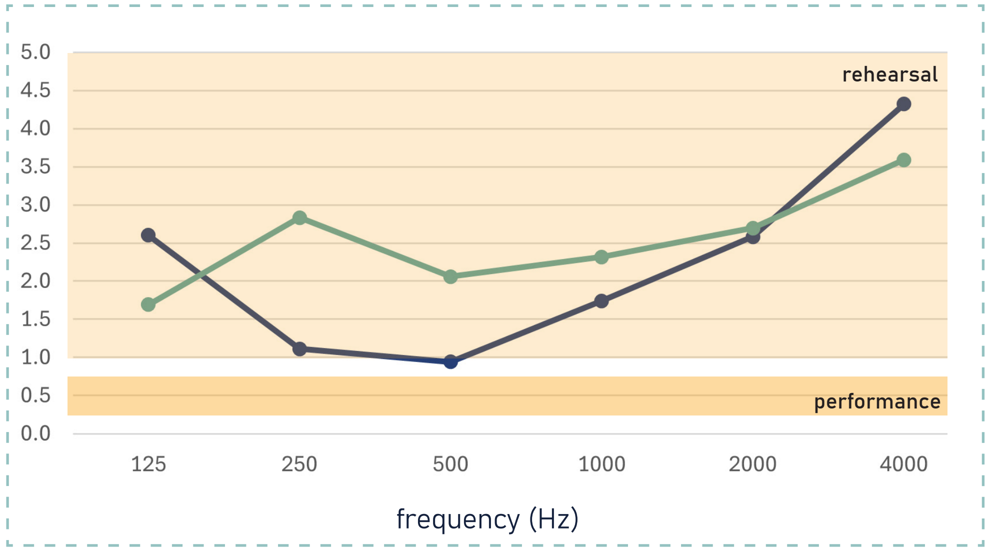
measured values (unoccupied scenario)

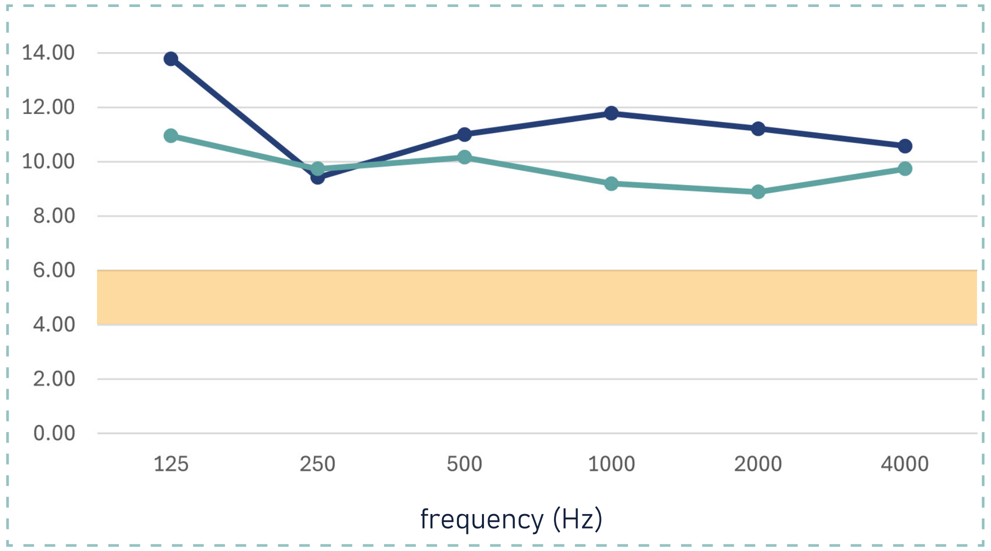
simulated values (occupied scenario)

VS.

target values







reverberation time

RT

clarity index (definition)

C80

acoustic strength

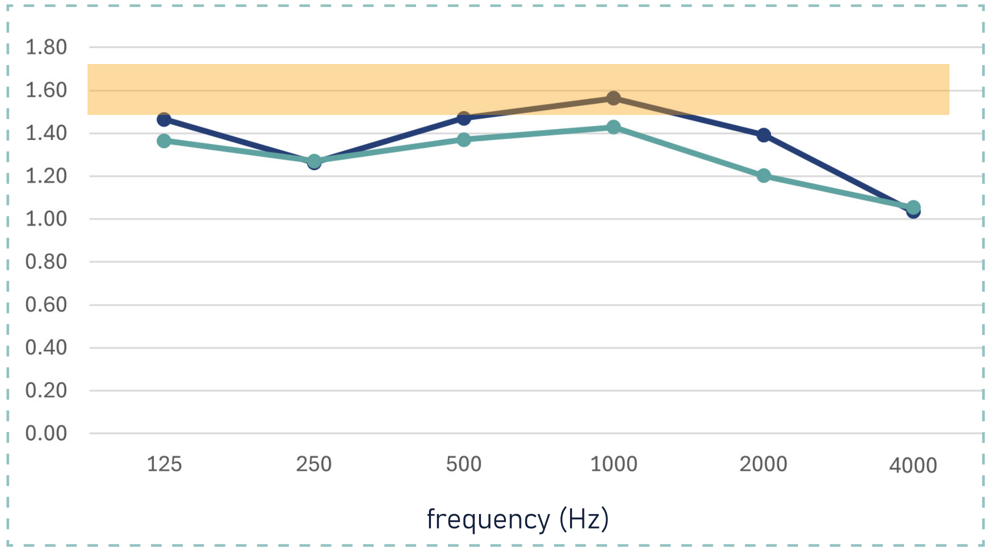
G

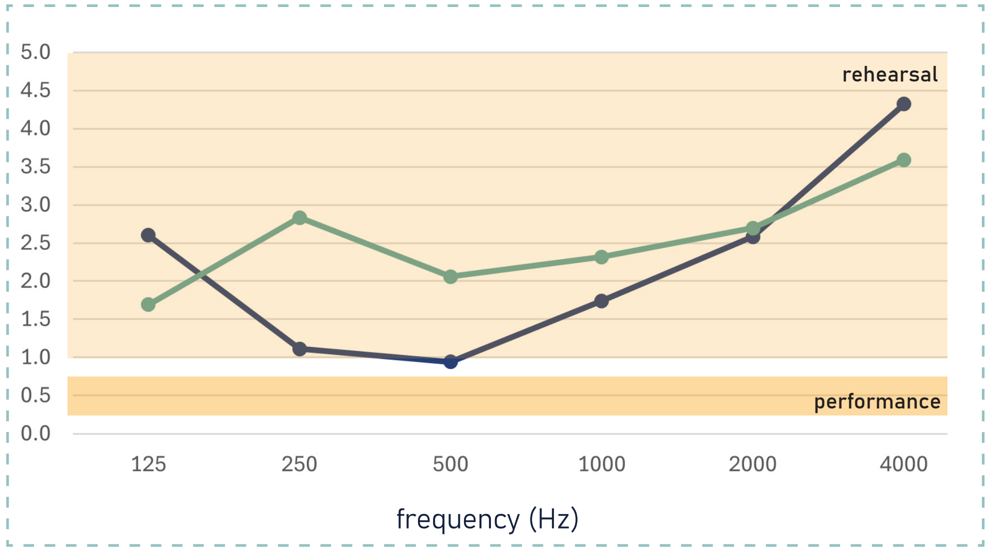
measured values (unoccupied scenario)

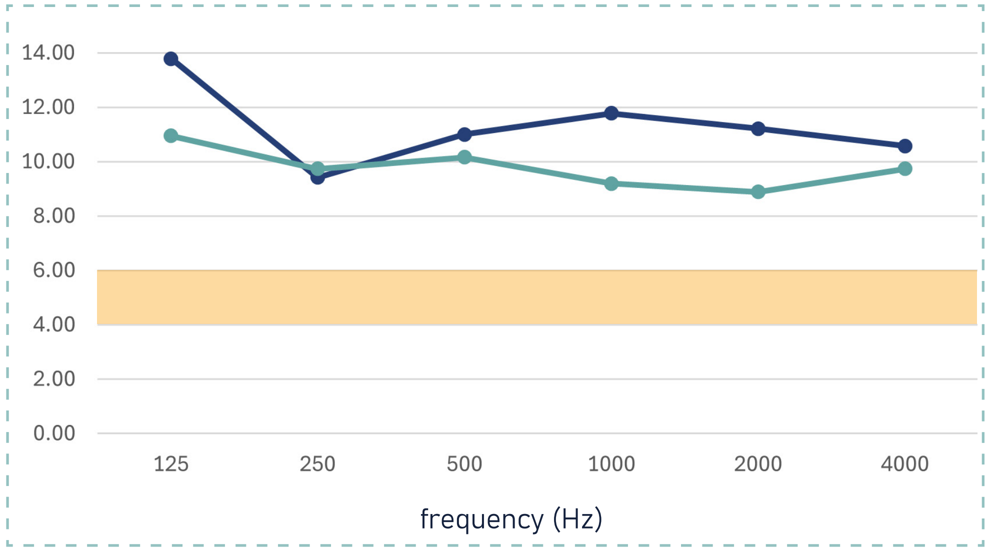
simulated values (occupied scenario)

VS.

target values







(slightly) too short

too high

too high

reverberation time

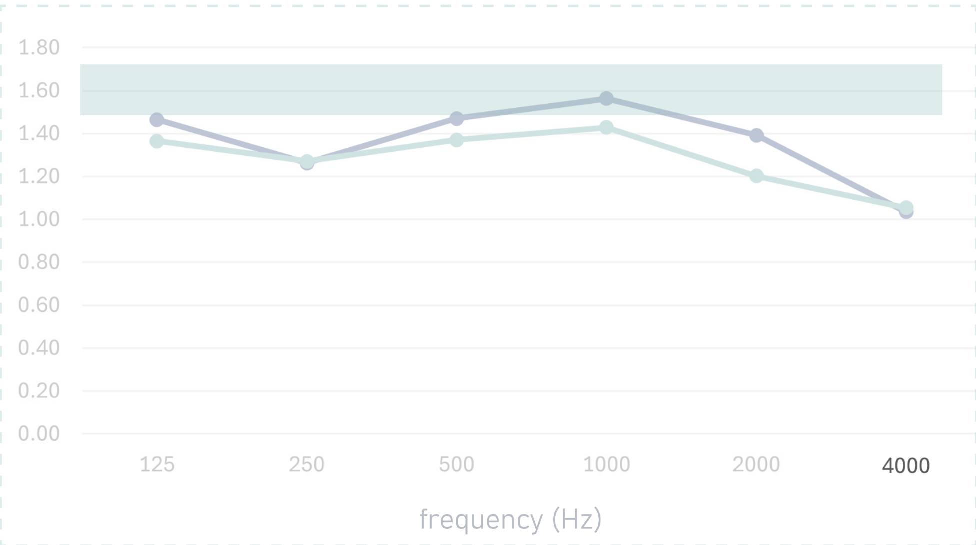
RT

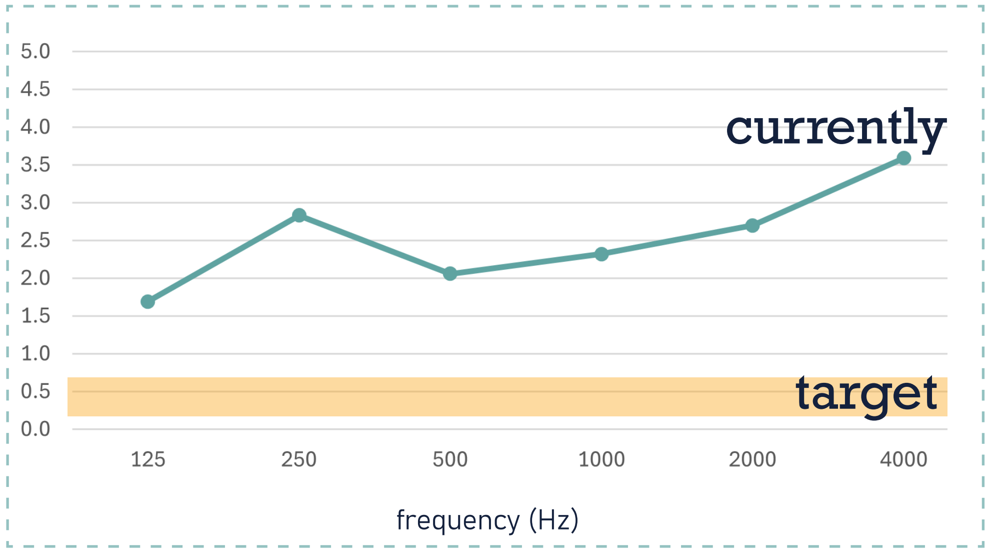
clarity index (definition)

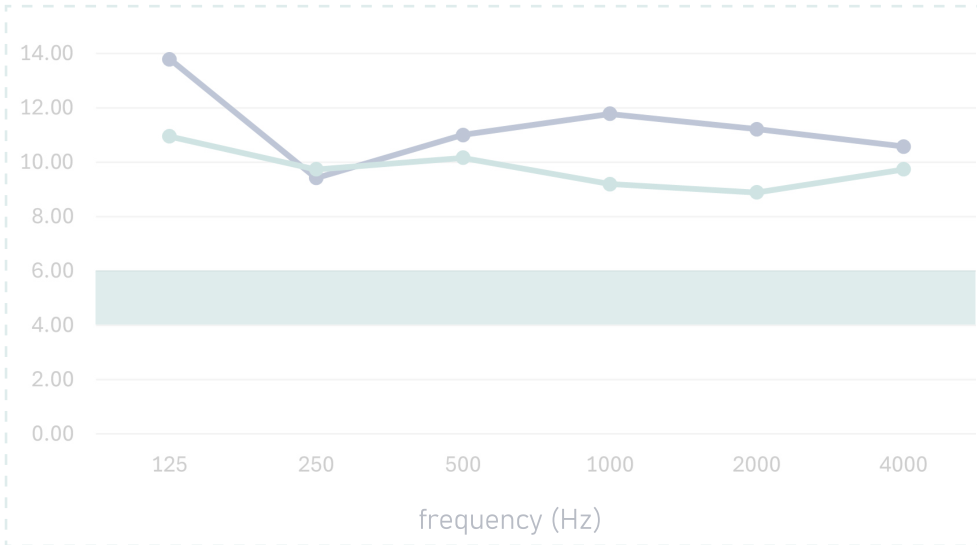
C80

acoustic strength

G







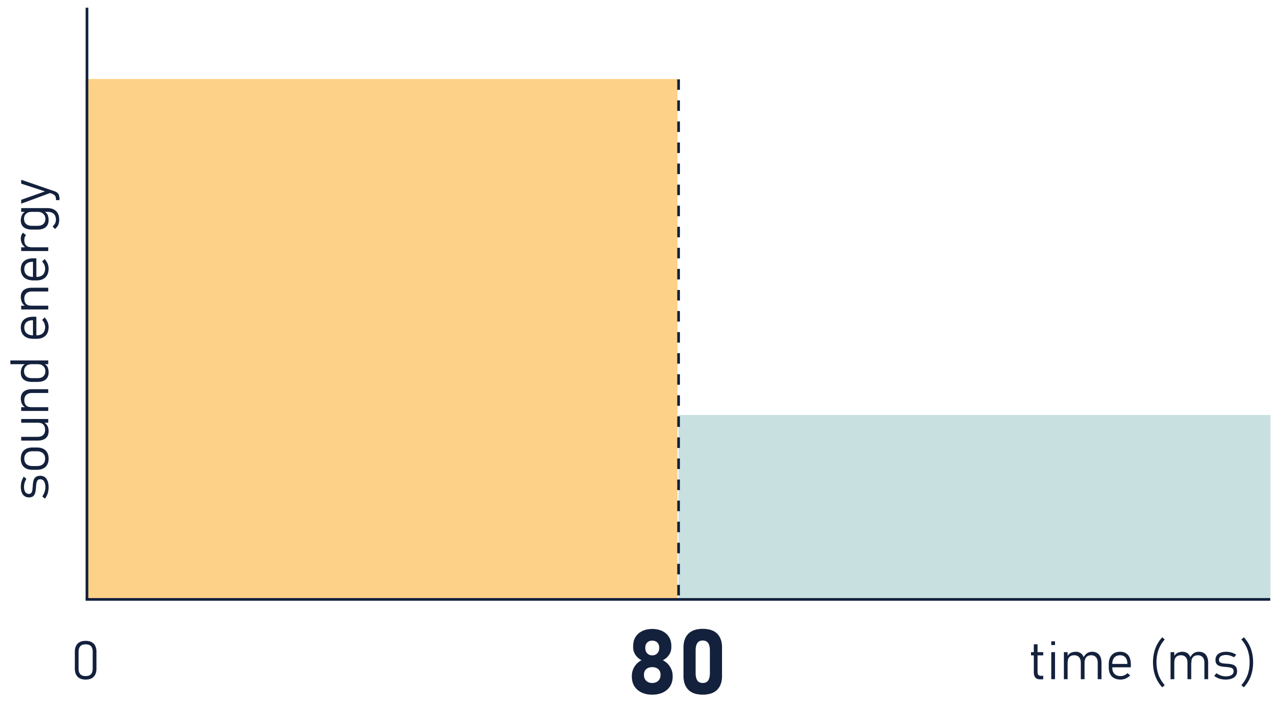
(slightly) too short

too high

too high

clarity index (definition)

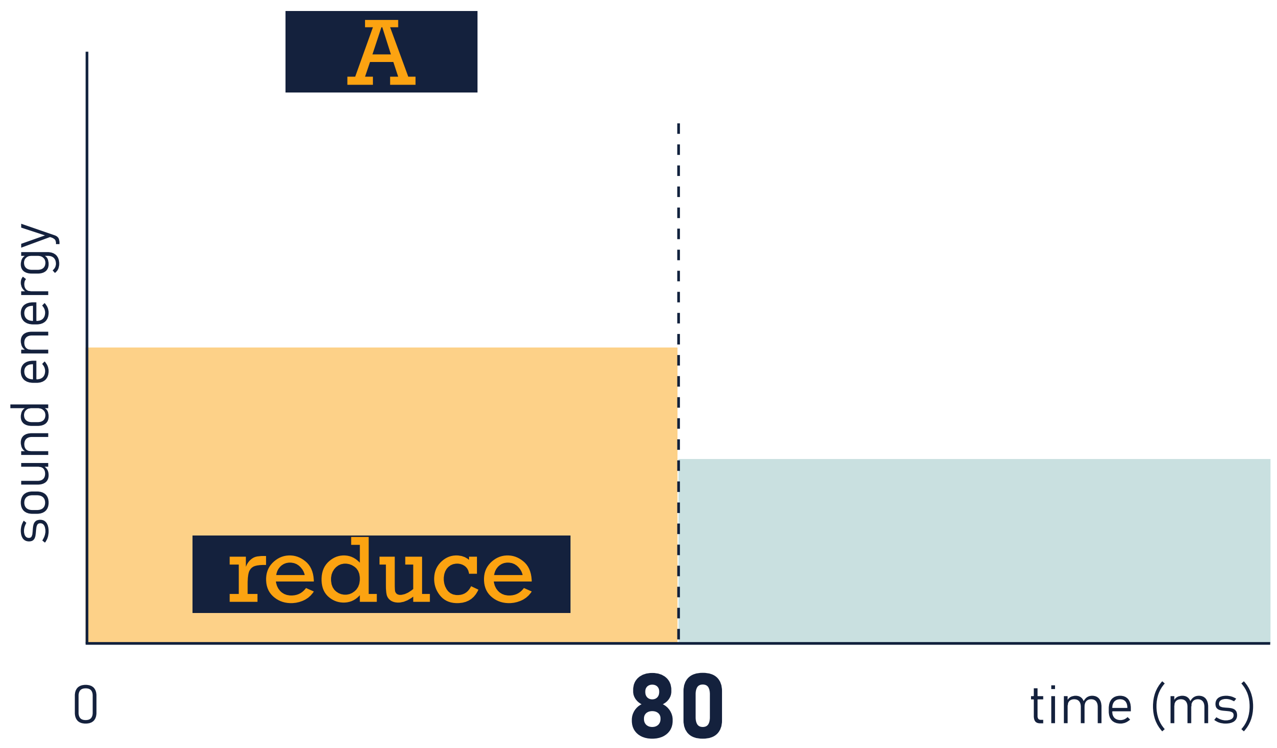
$$C80 = \frac{\text{Early}}{\text{Late}}$$



clarity index (definition)

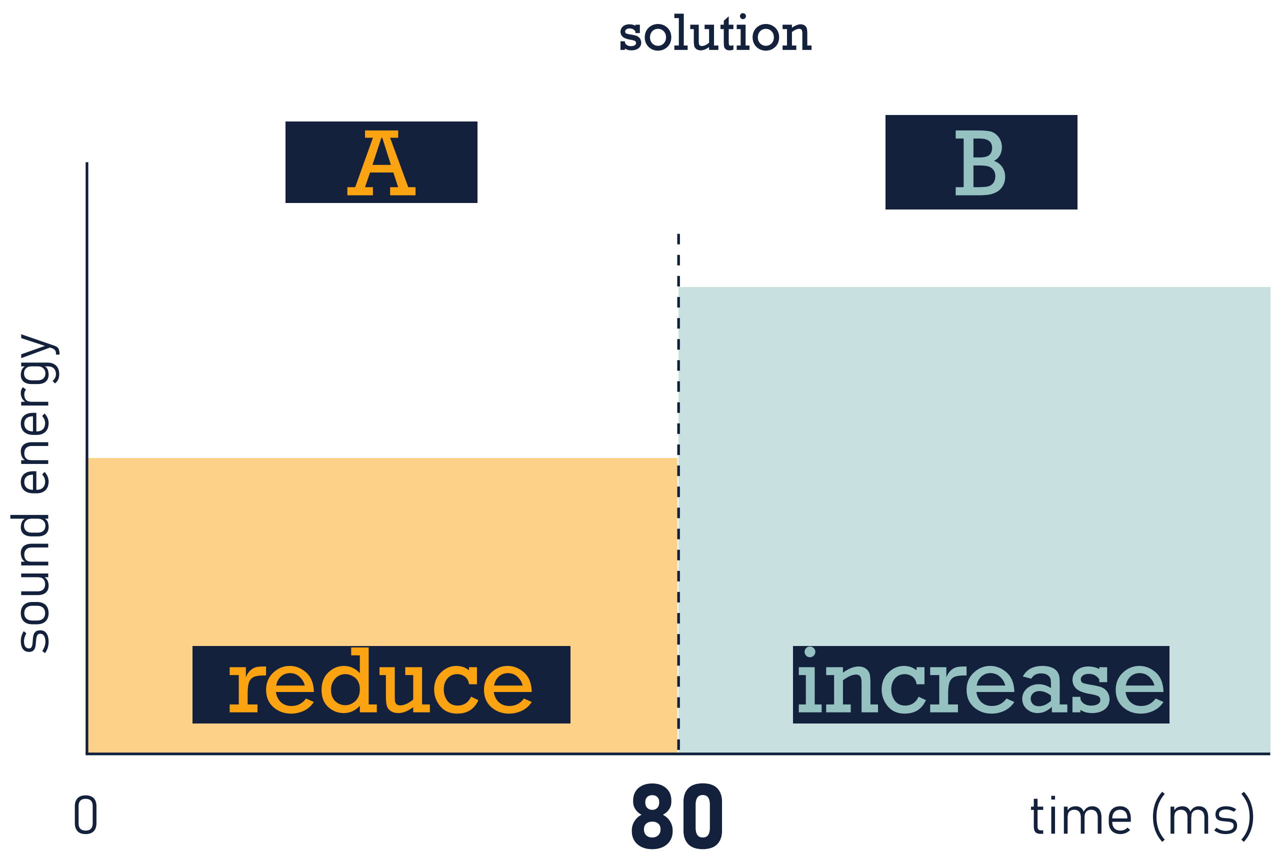
$$C80 = \frac{\text{Early}}{\text{Late}}$$

solution



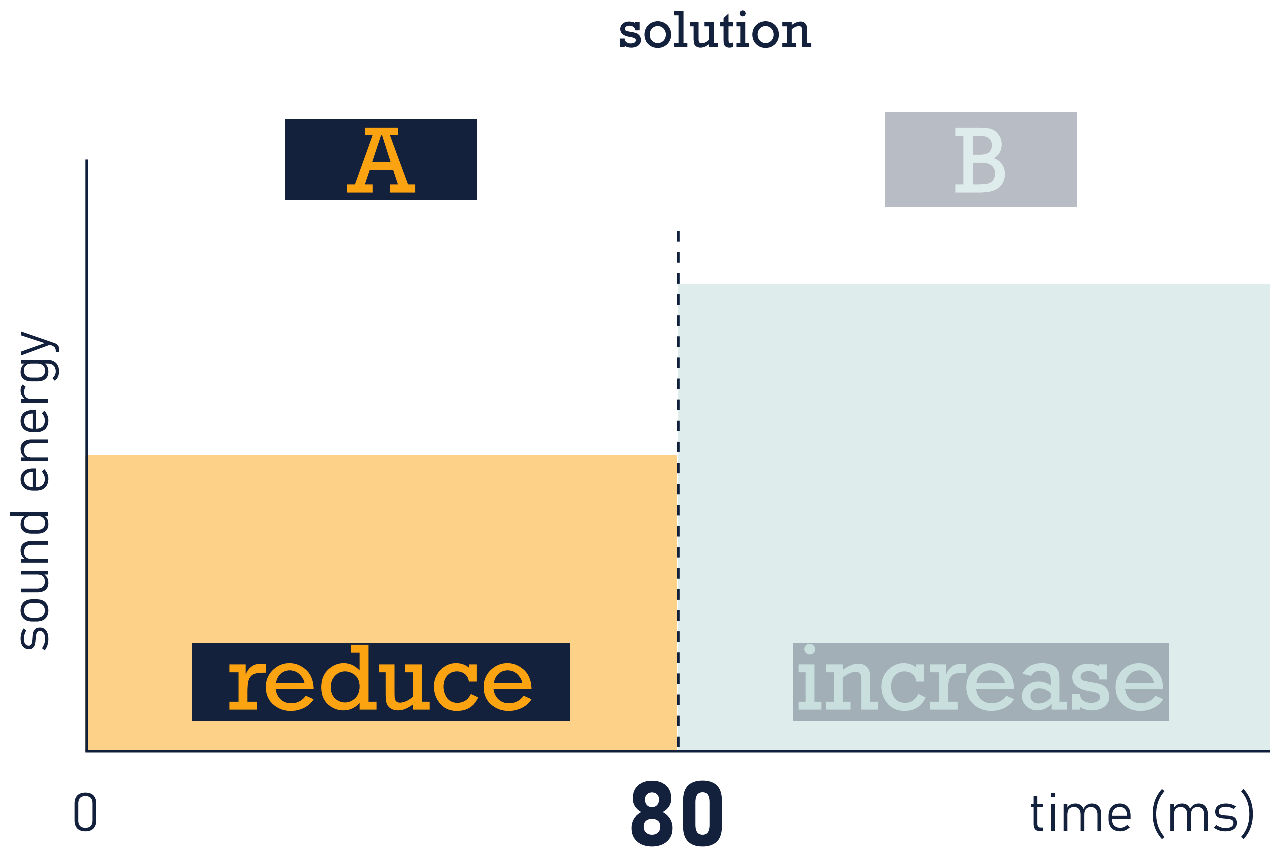
clarity index (definition)

$$C80 = \frac{\text{Early}}{\text{Late}}$$



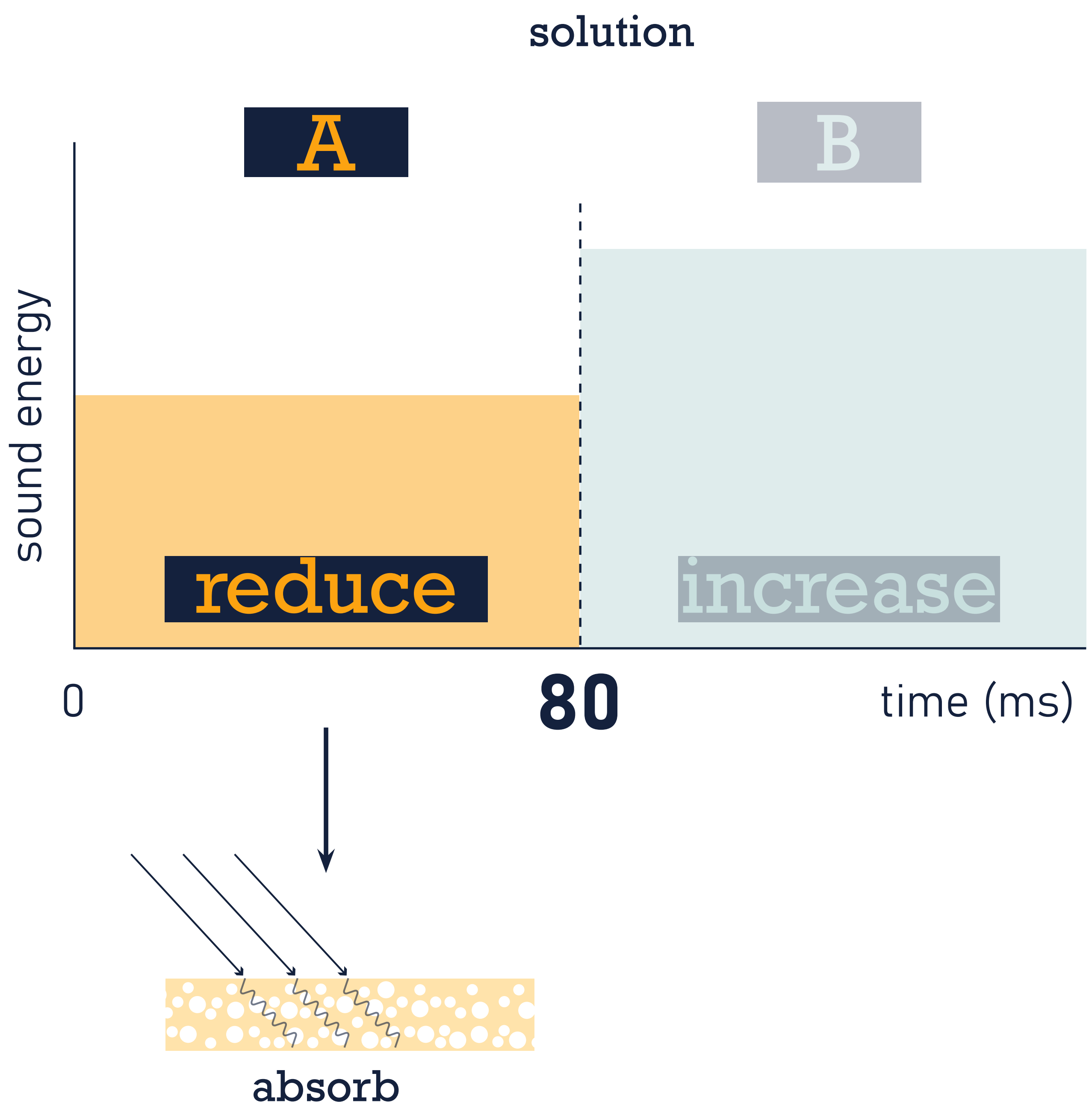
clarity index (definition)

$$C80 = \frac{Early}{Late}$$

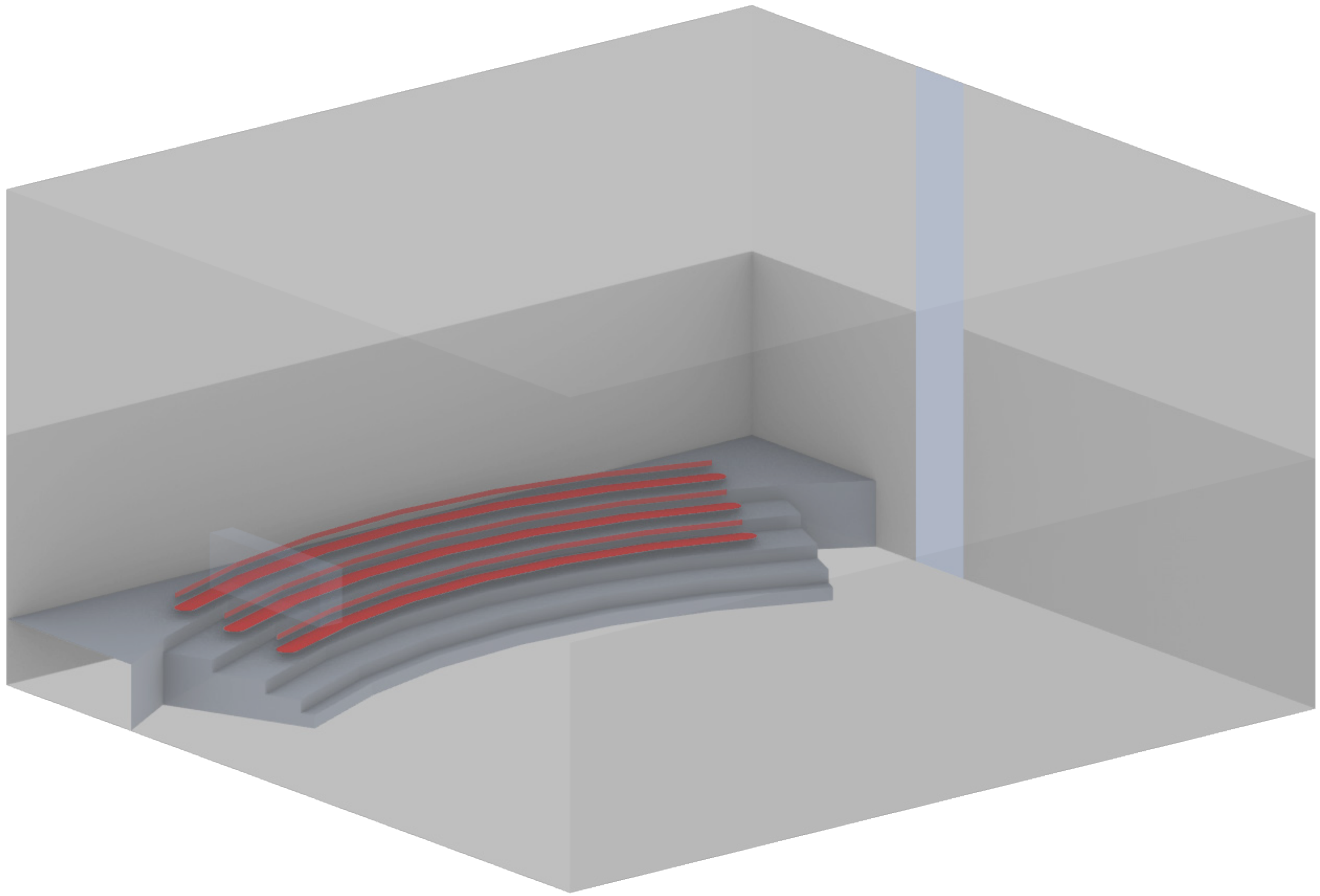


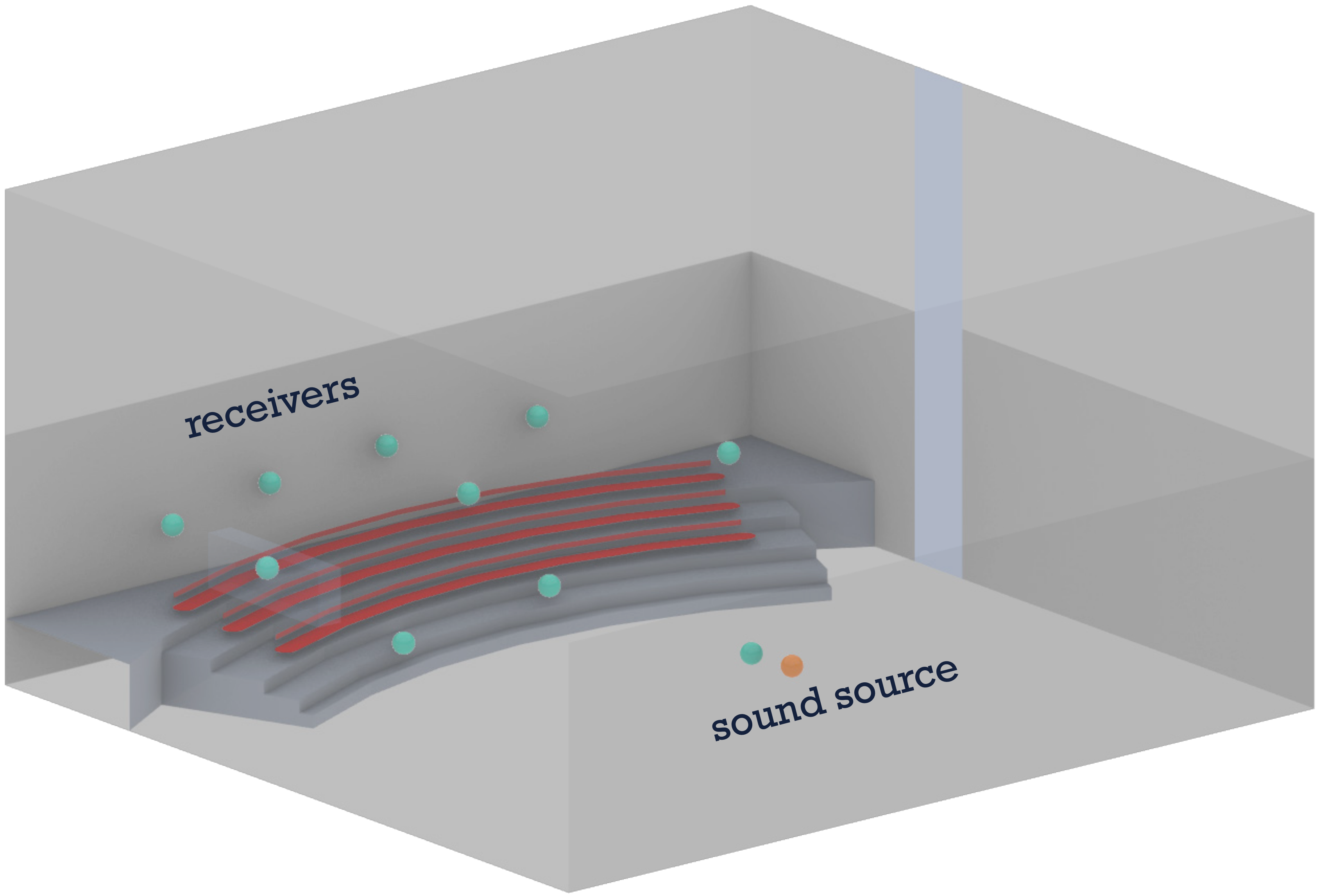
clarity index (definition)

$$C80 = \frac{\text{Early}}{\text{Late}}$$

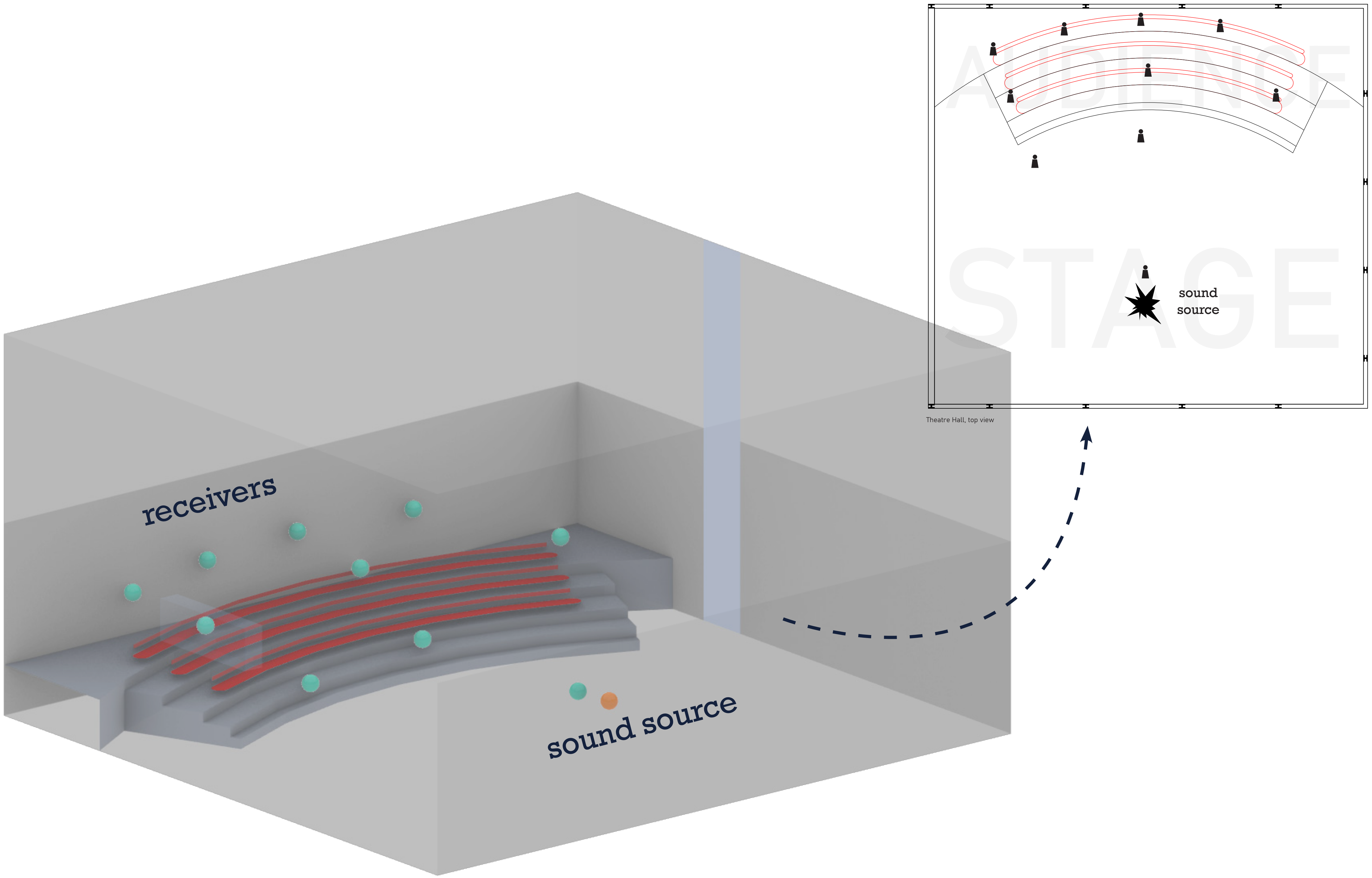


reducing early sound



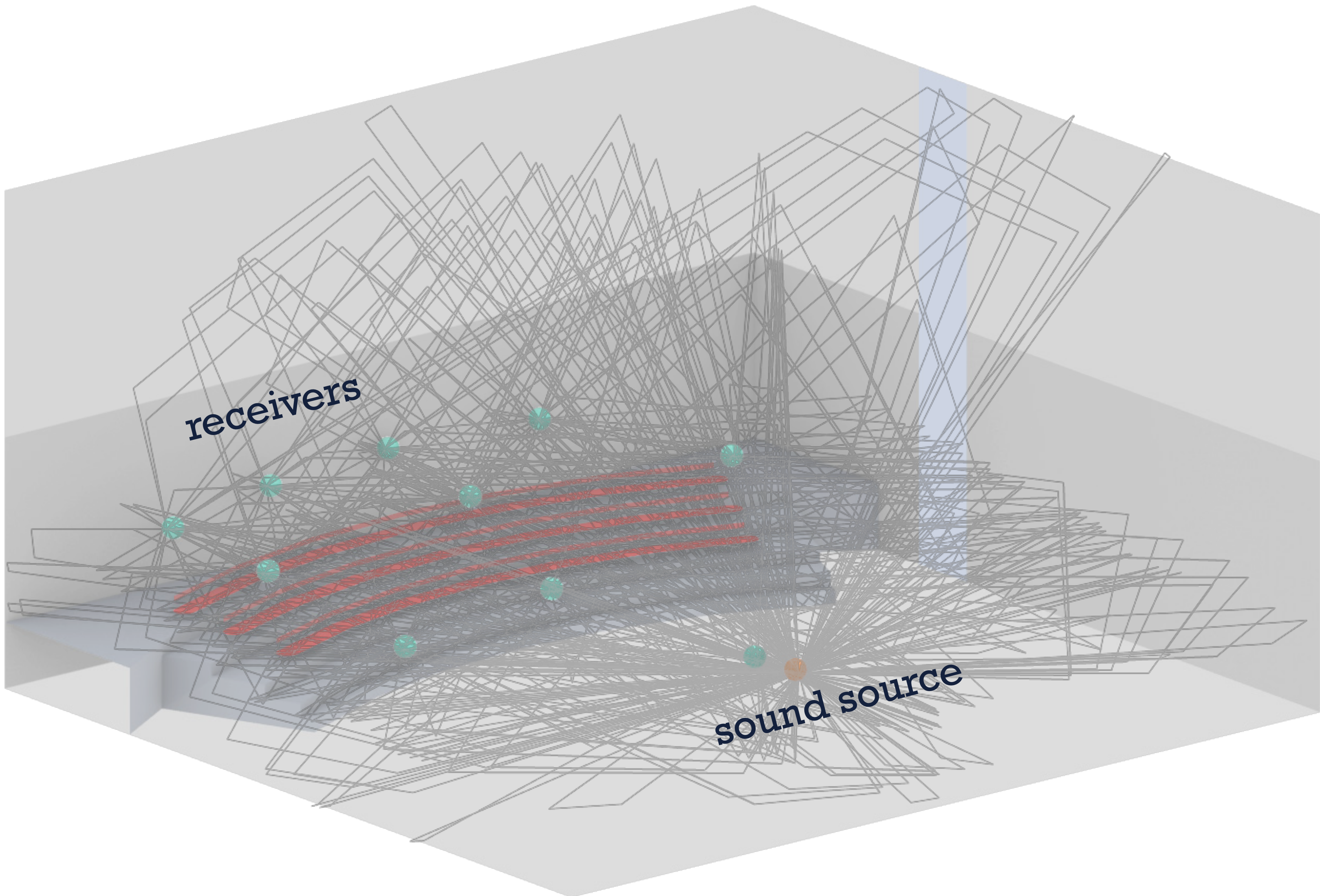

receivers
sound source

reducing early sound

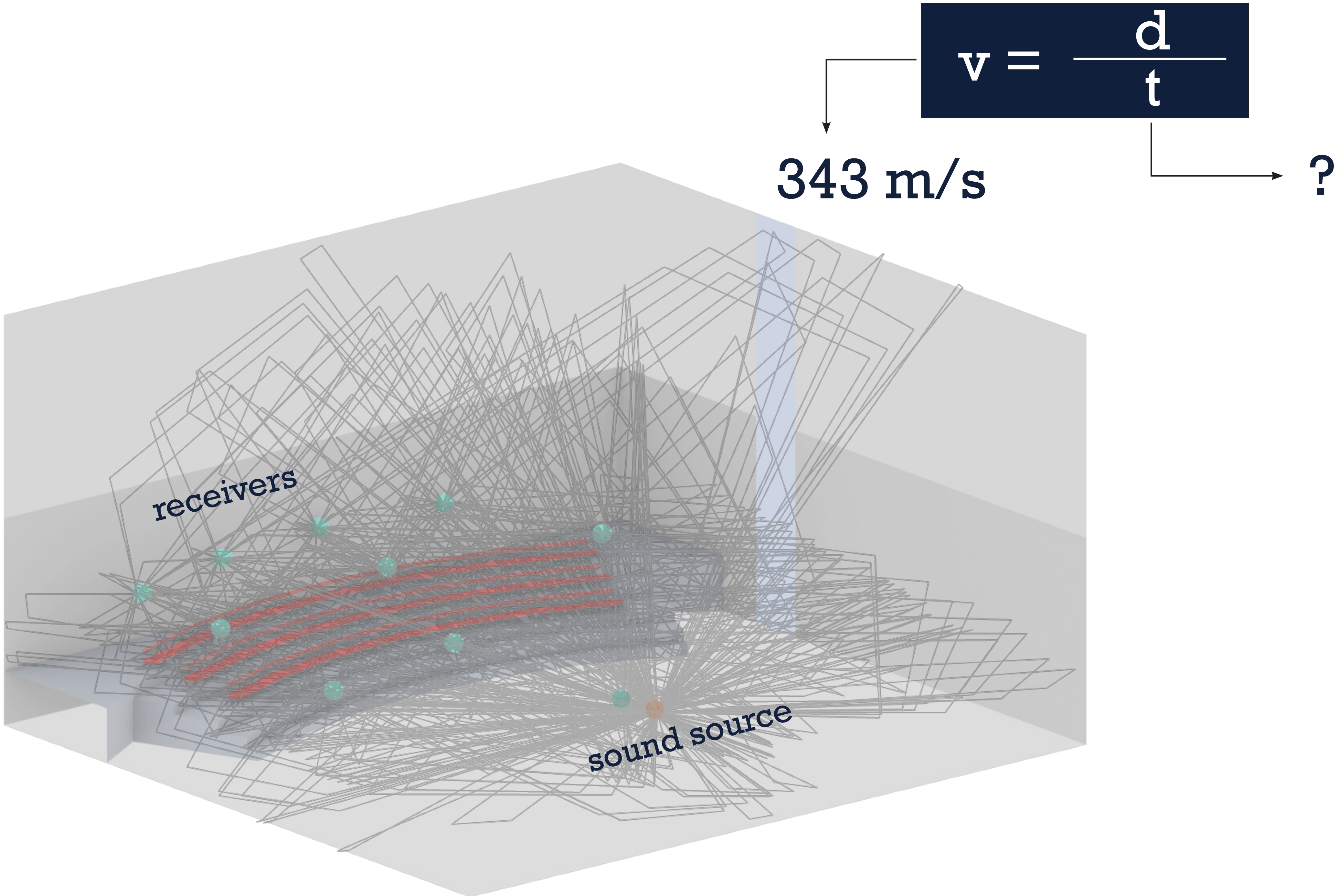


Theatre Hall, top view

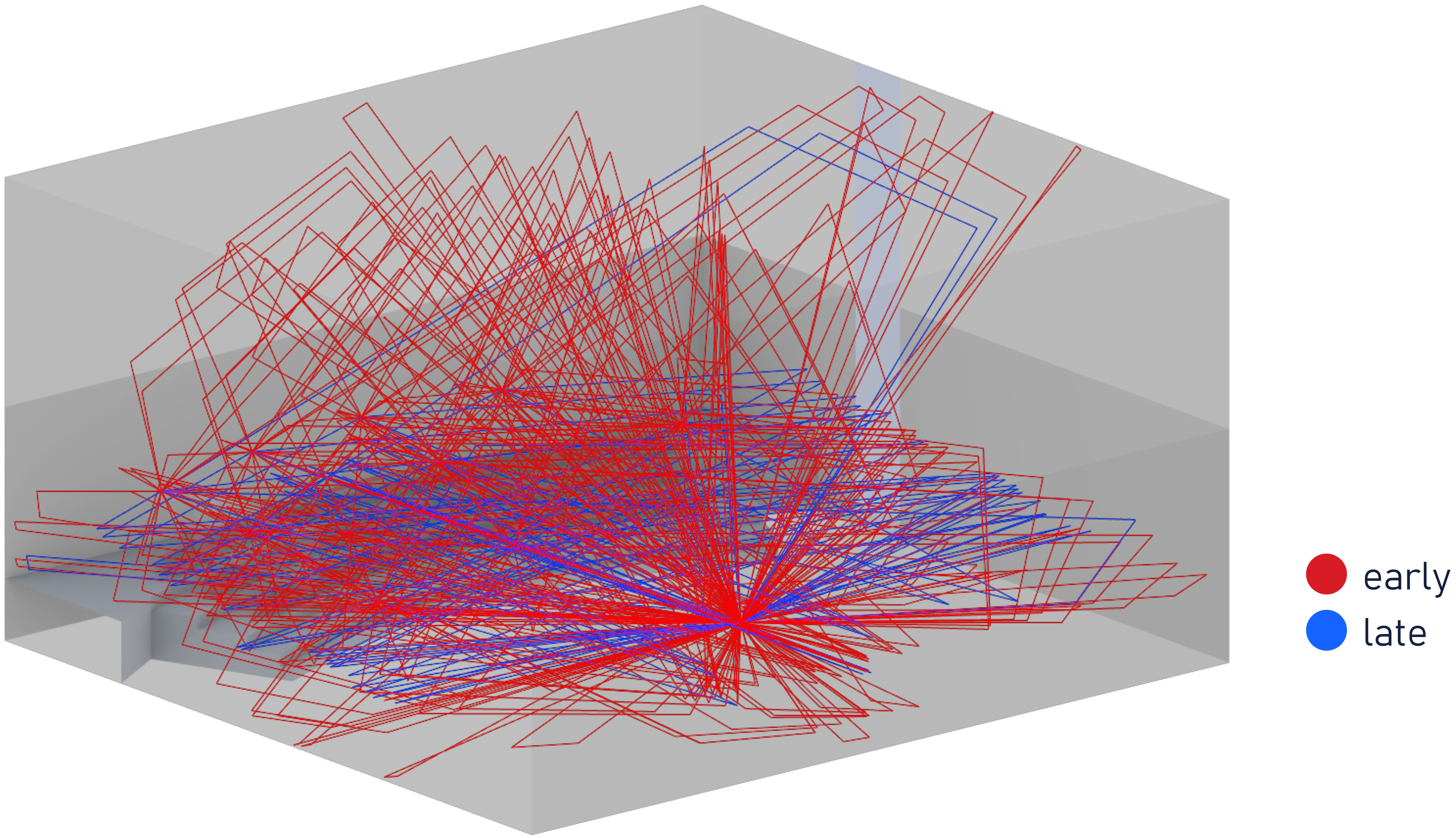
reducing early sound



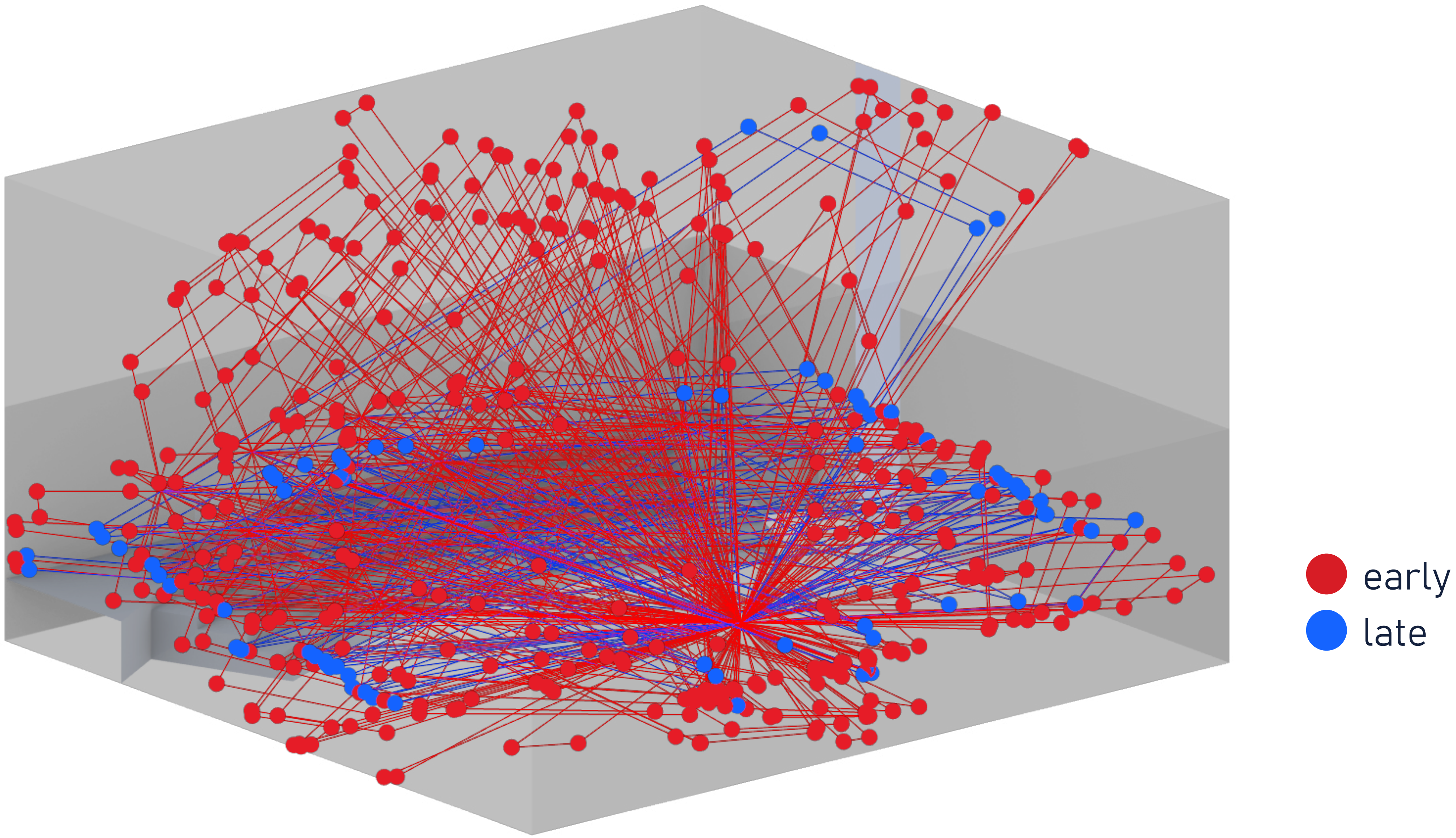
reducing early sound



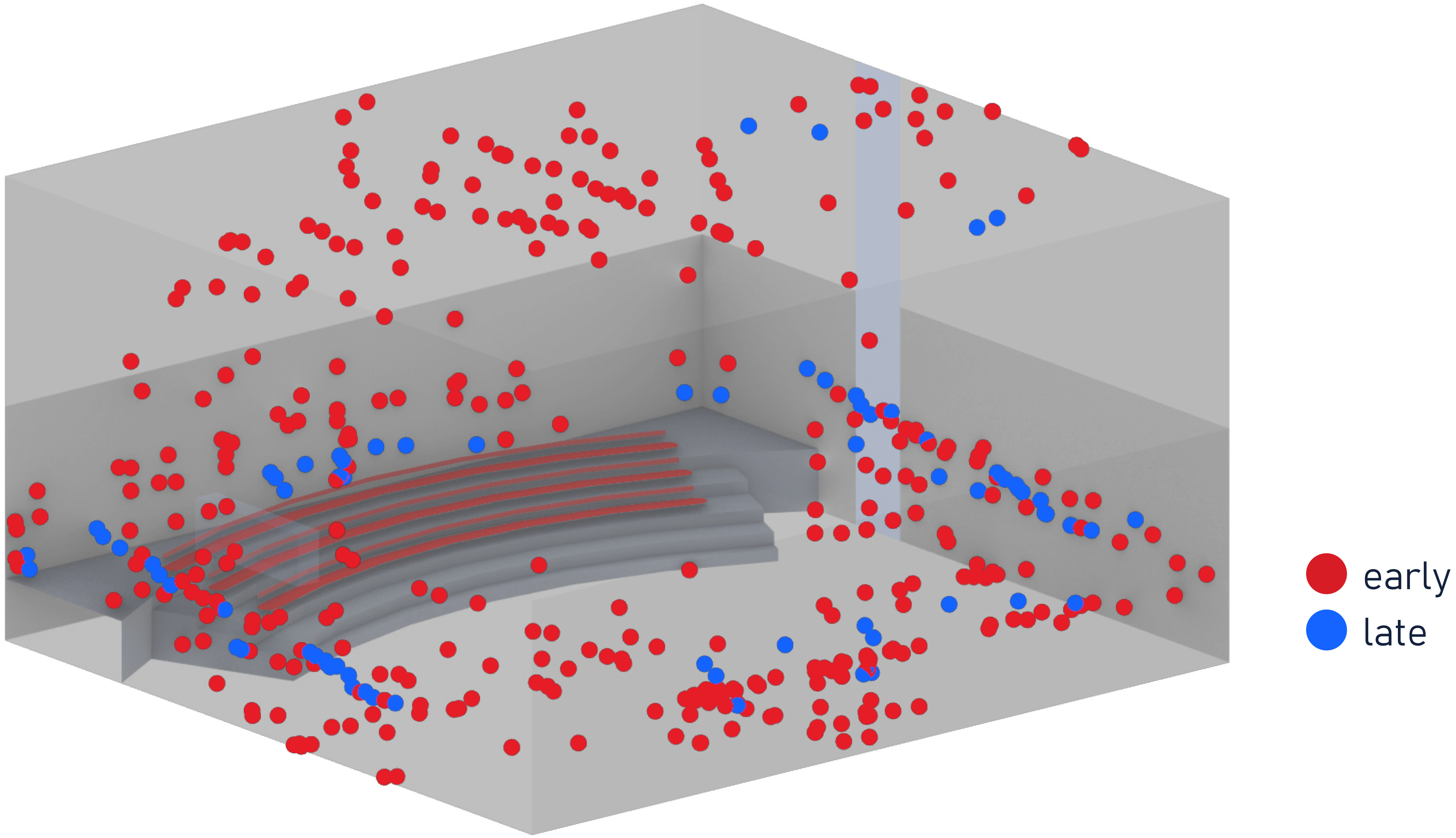
reducing early sound



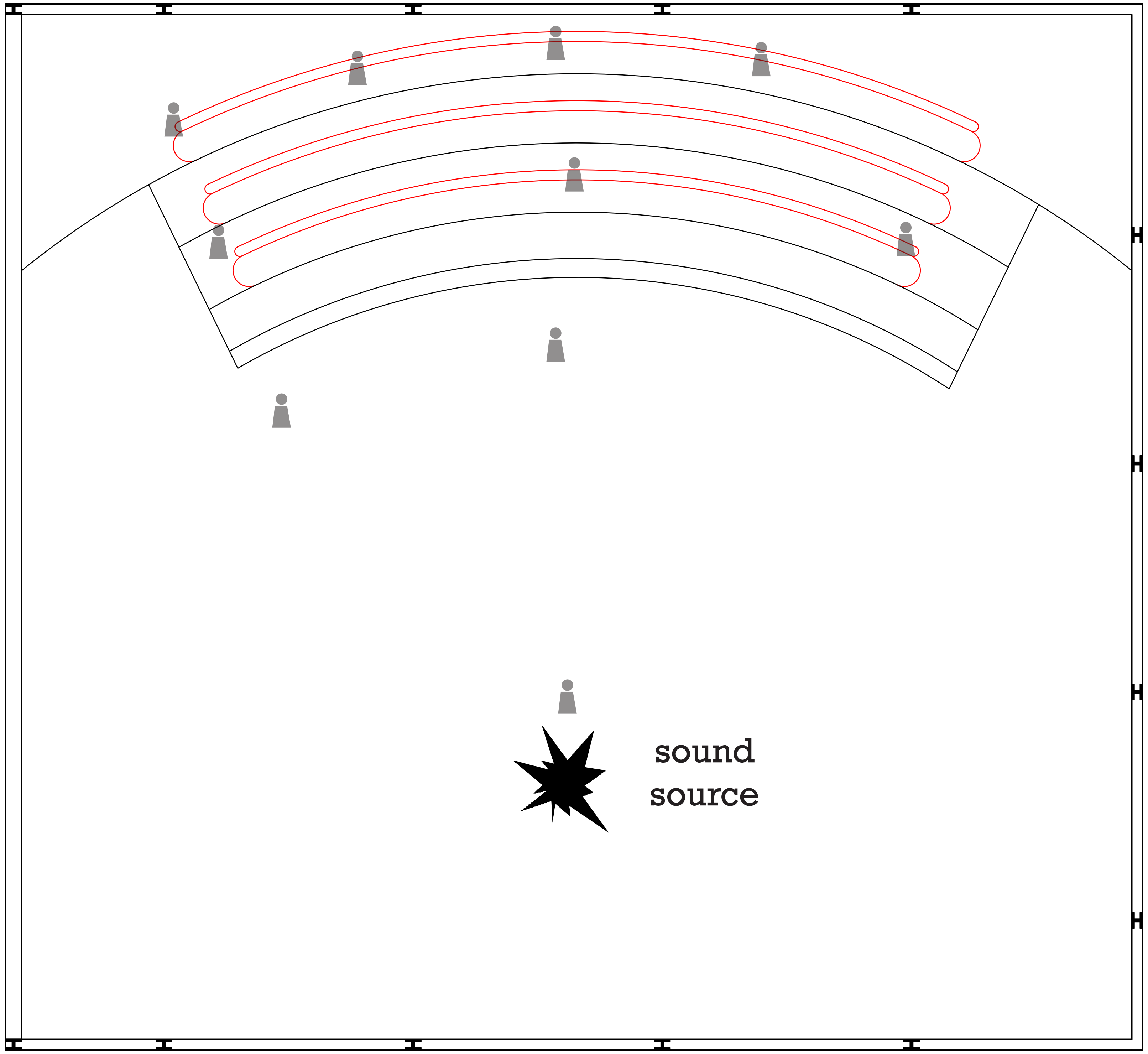
reducing early sound



reducing early sound

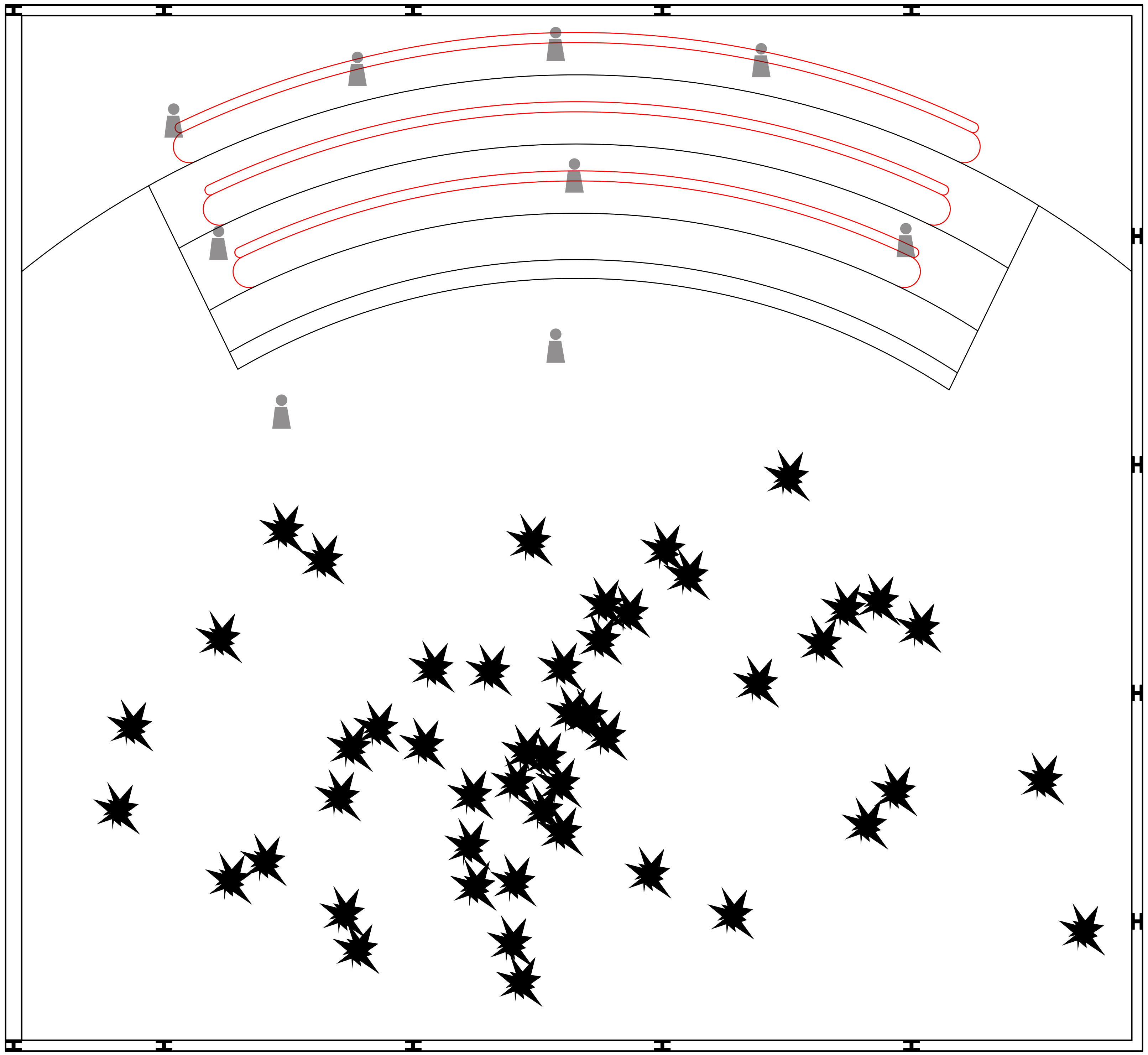


reducing early sound



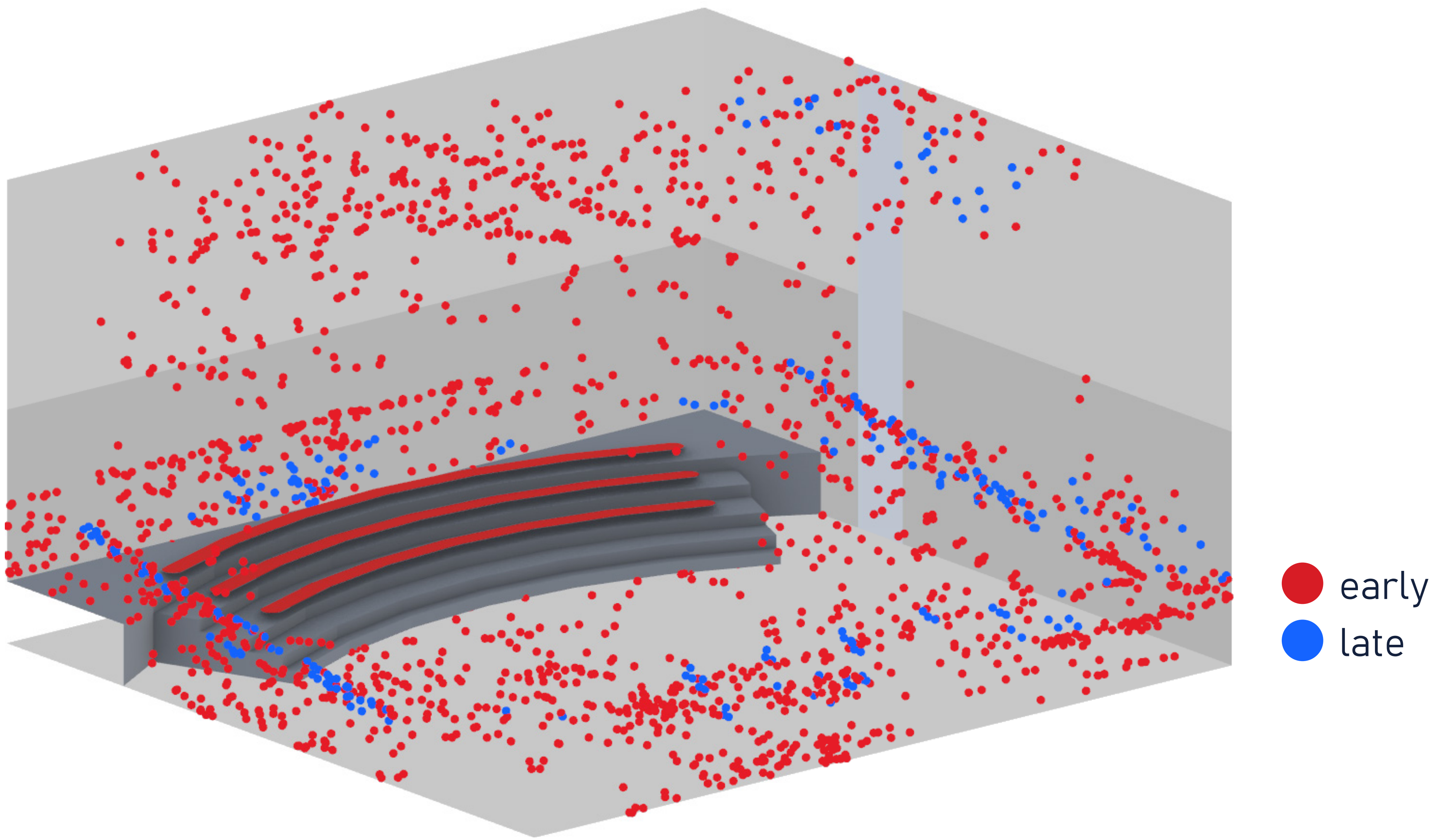
Theatre Hall, top view

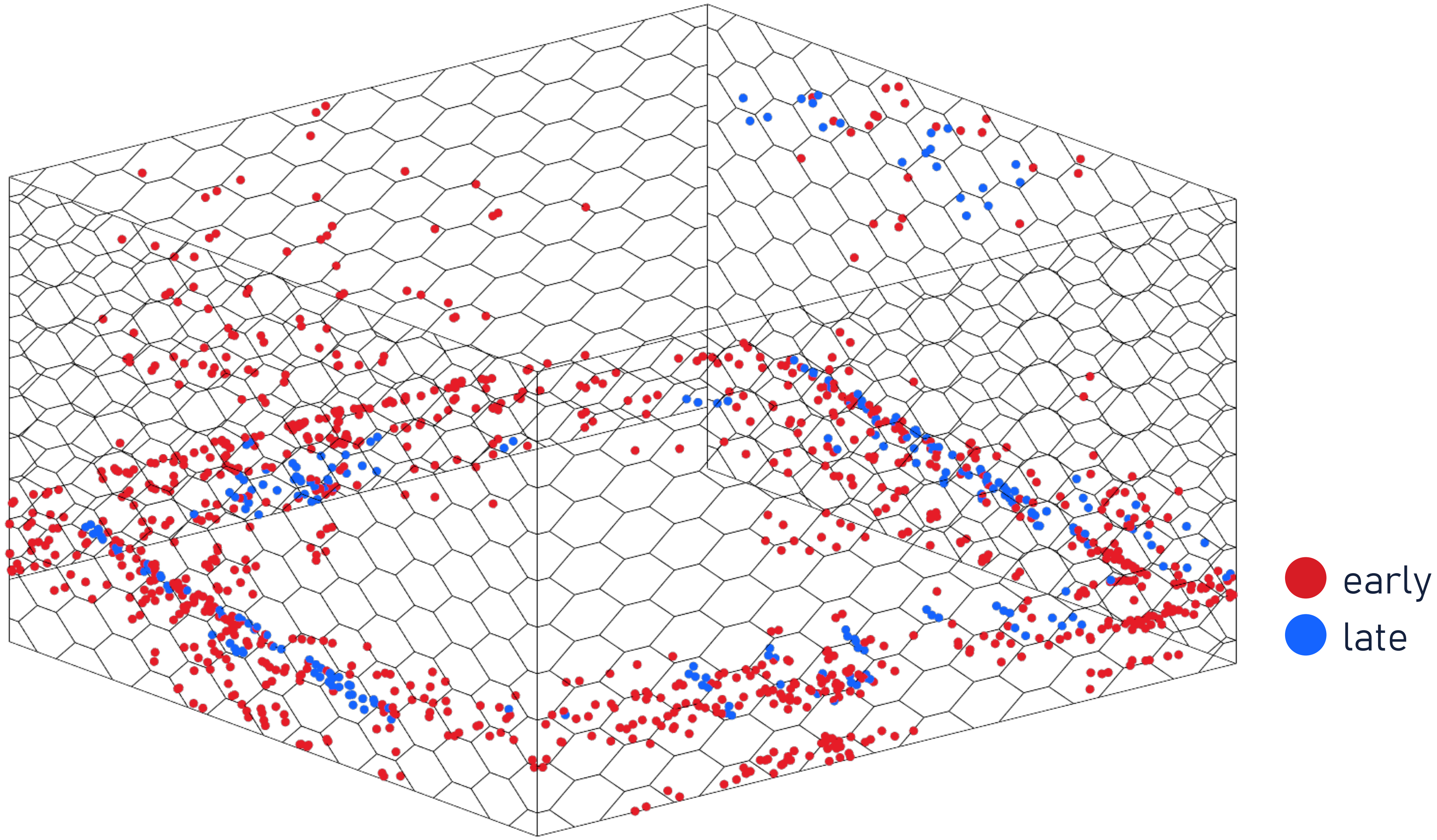
reducing early sound

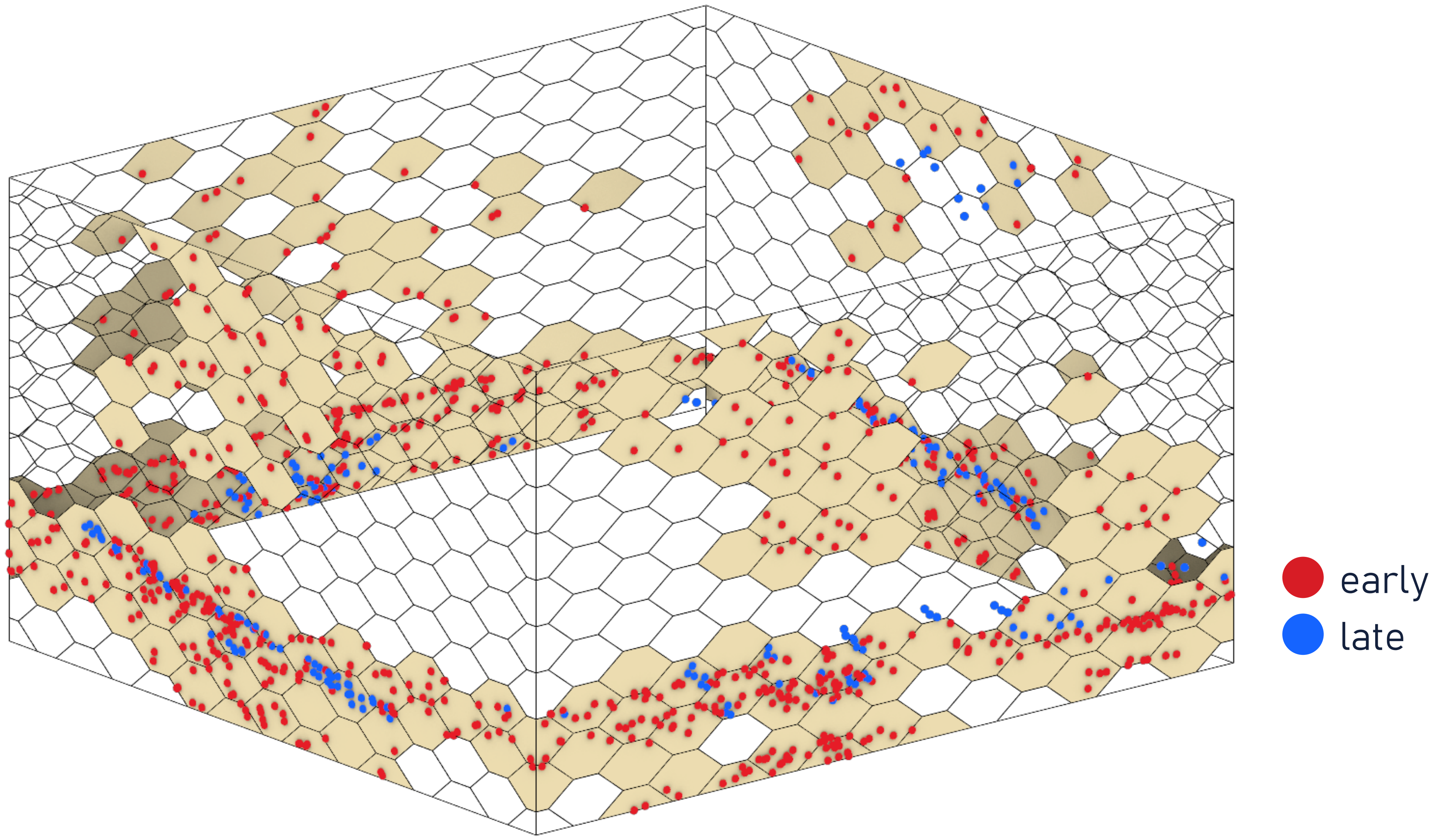


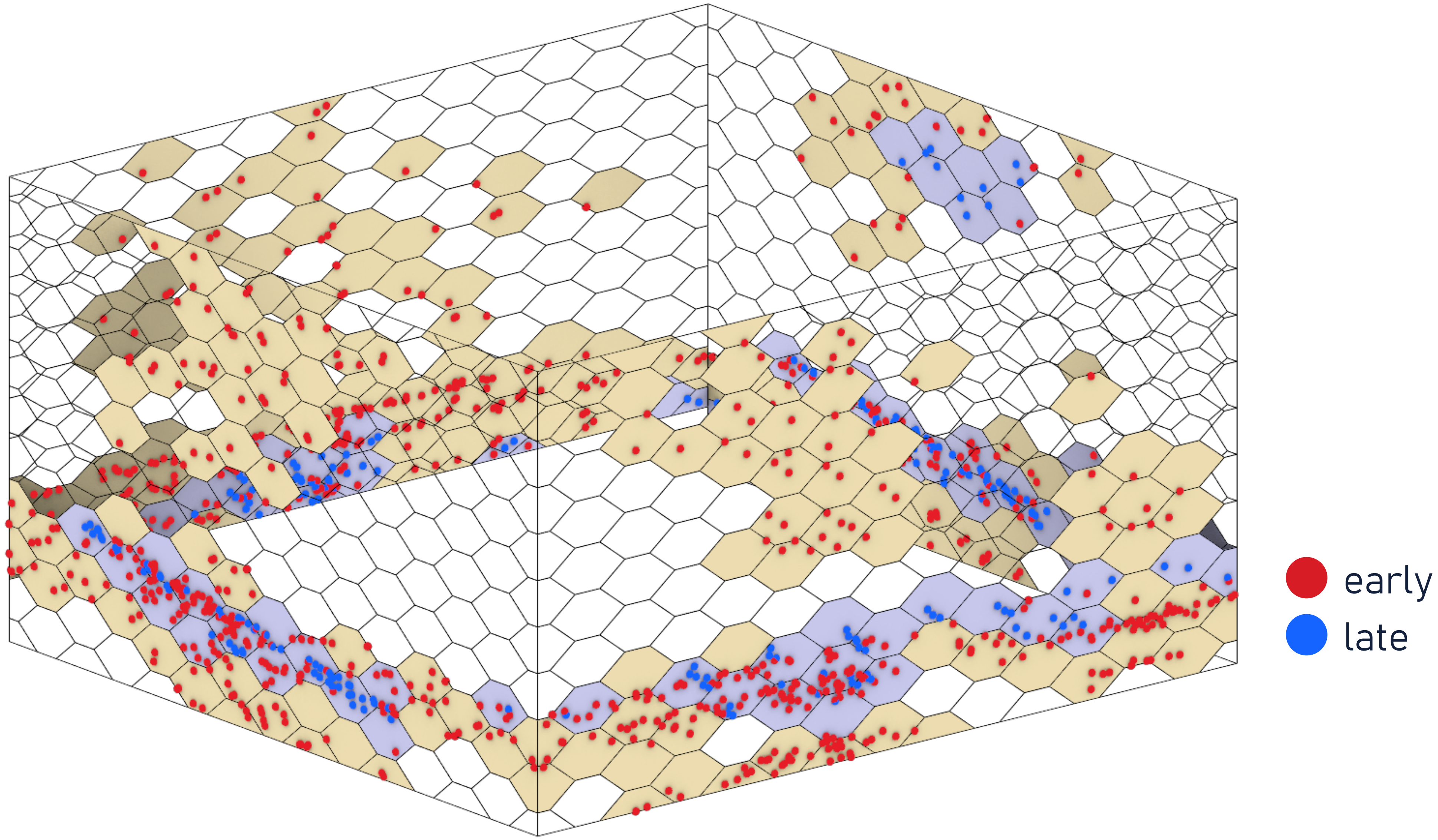
Theatre Hall, top view

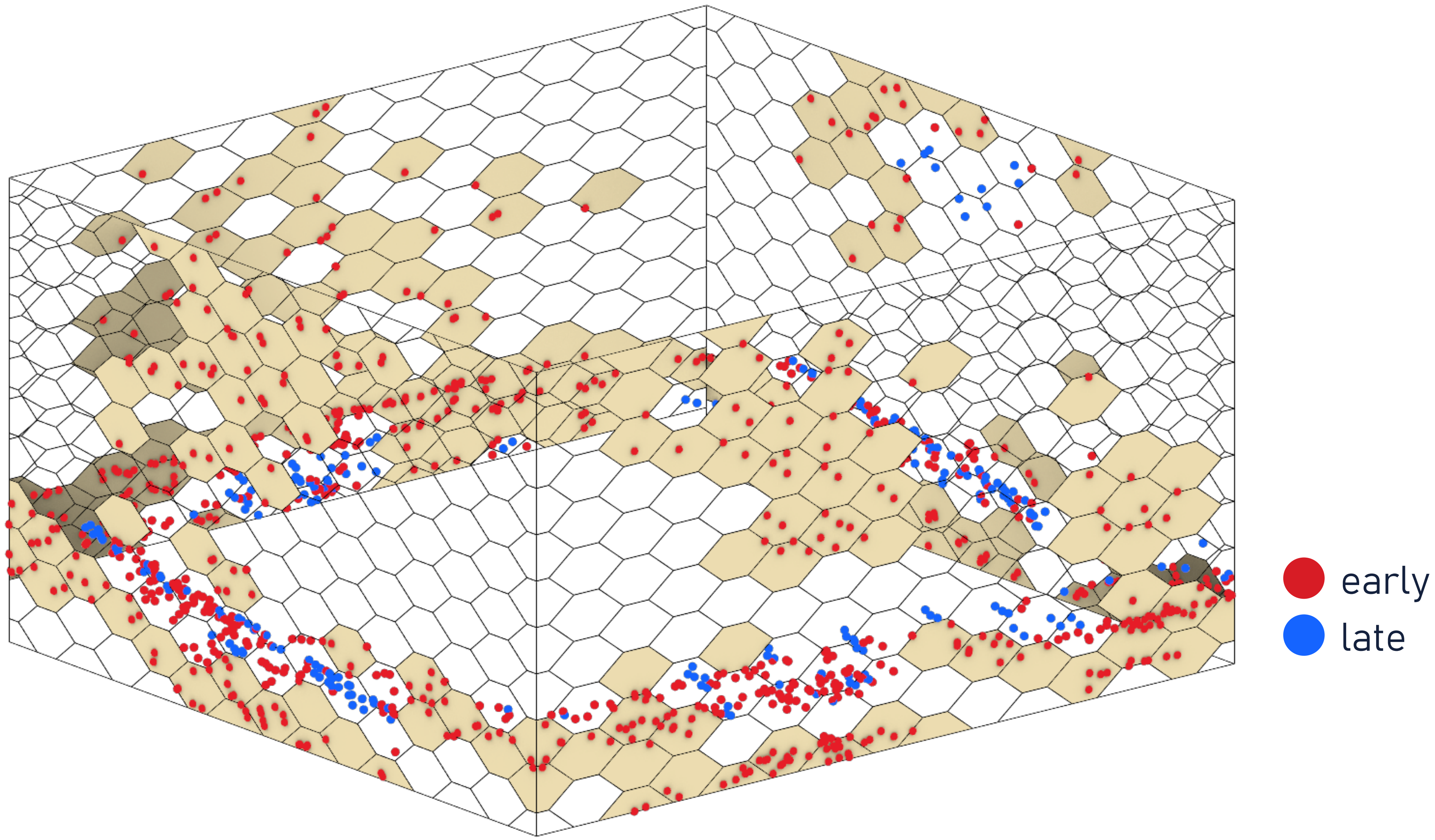
reducing early sound




early
late

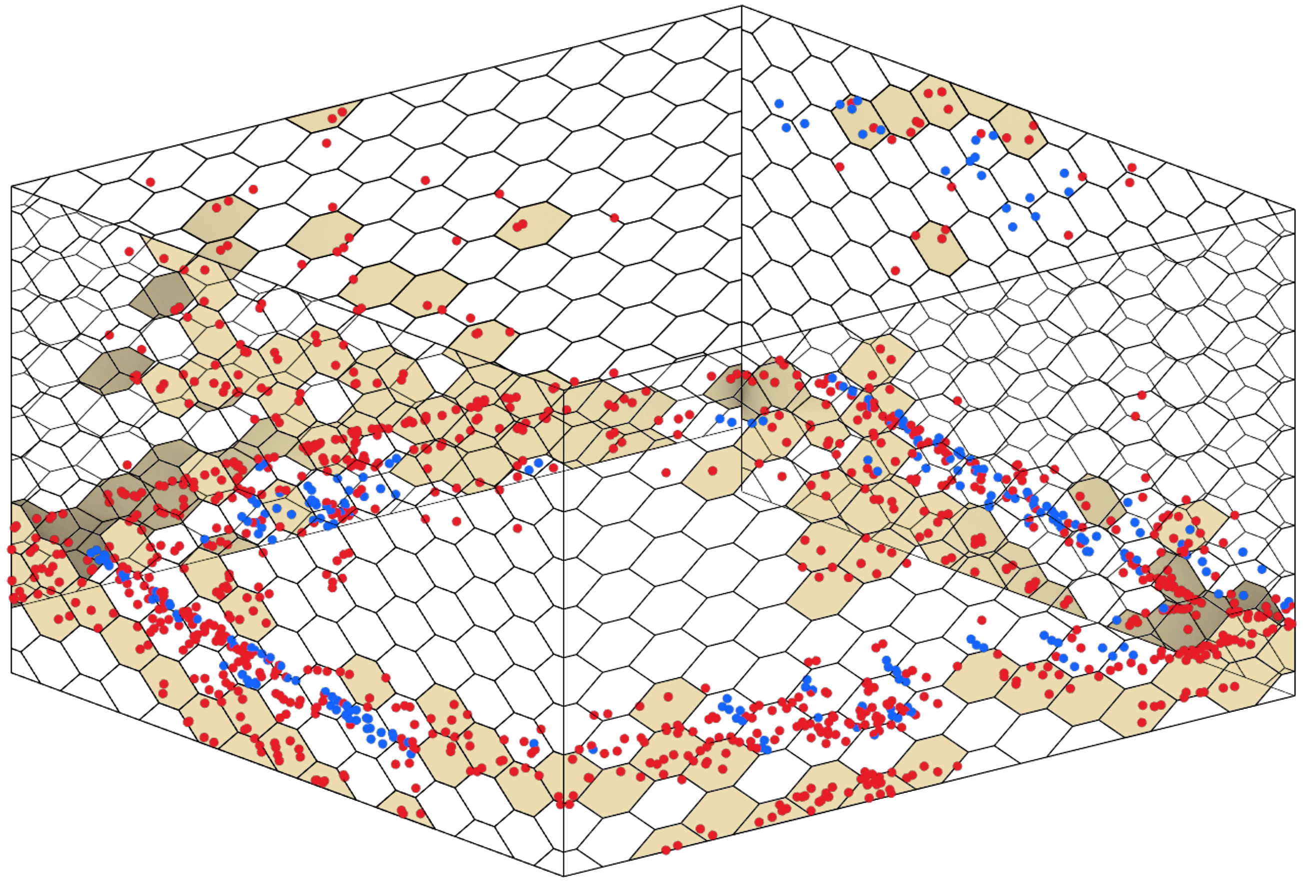

early
late

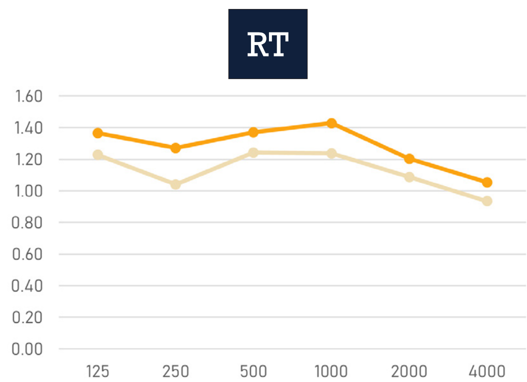

early
late

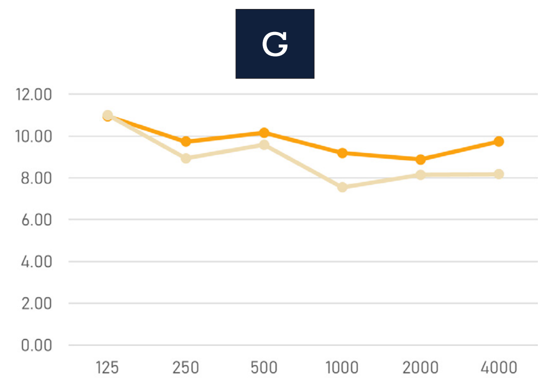

early
late

reducing early sound

125 panels
73m²

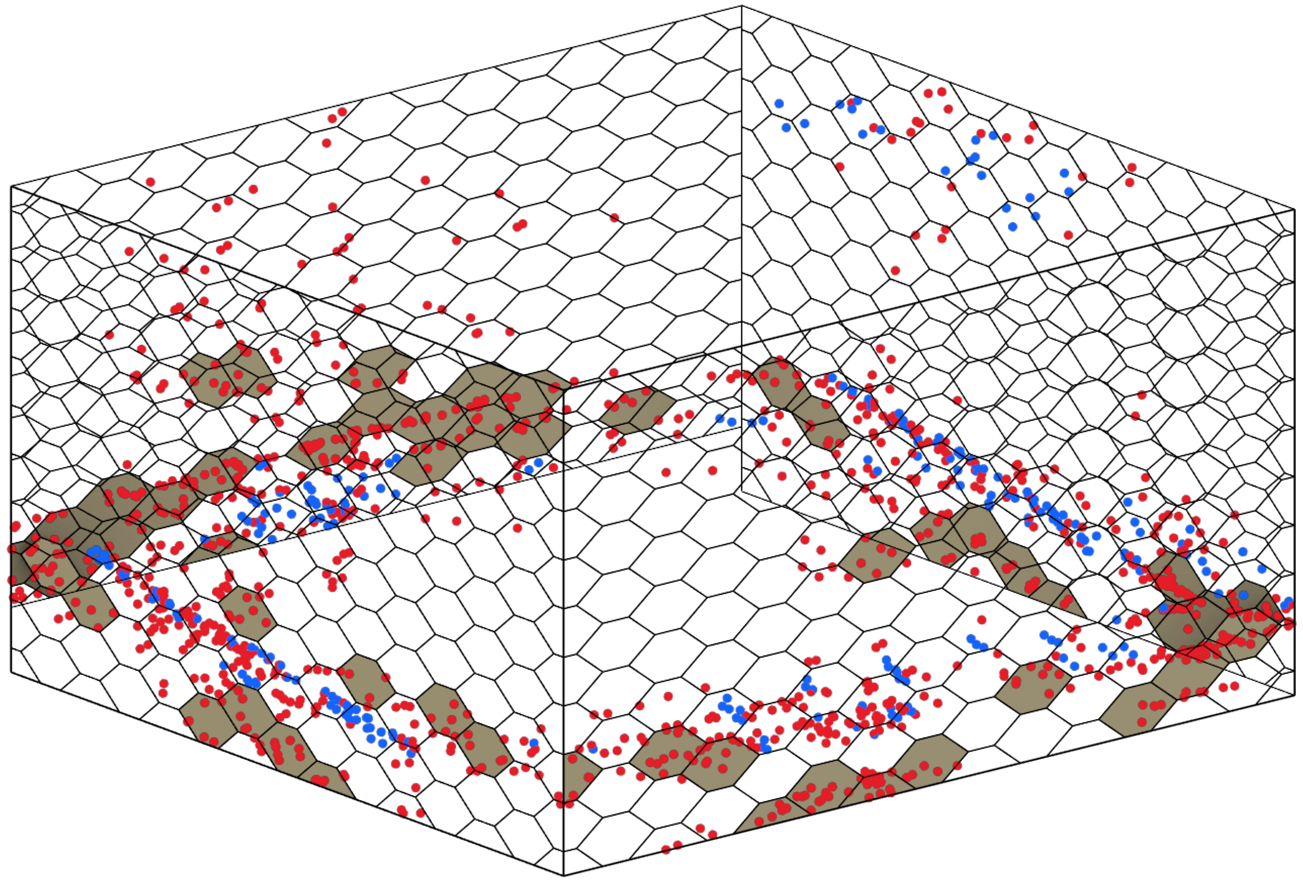


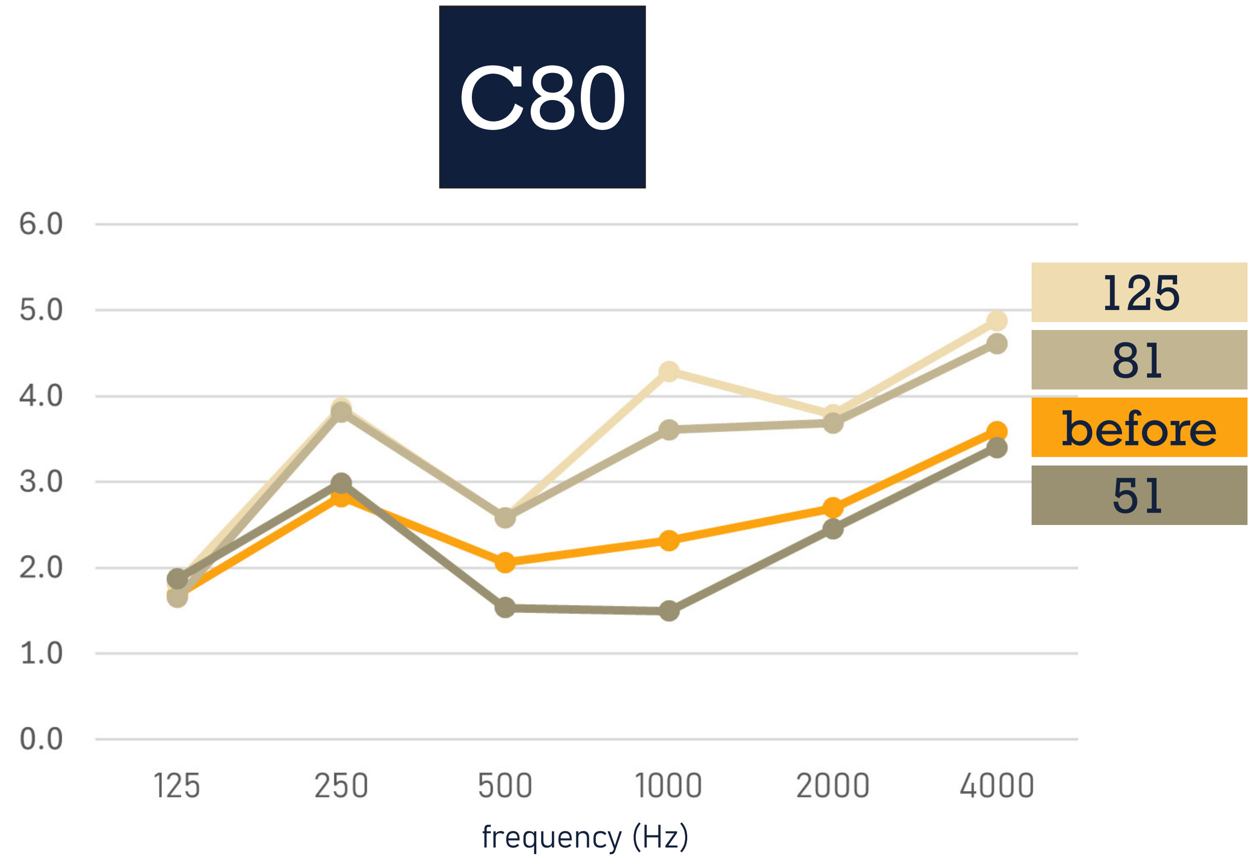


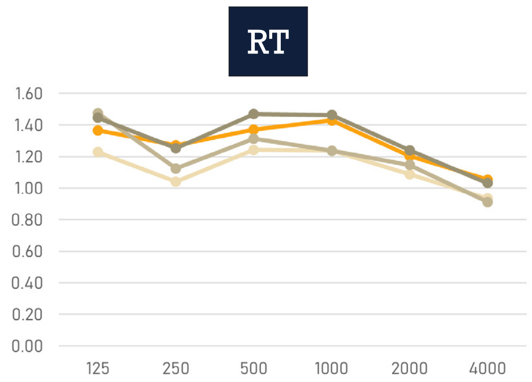


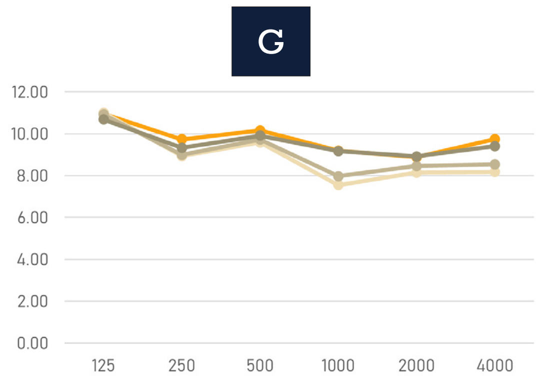
reducing early sound

51 panels
29m²

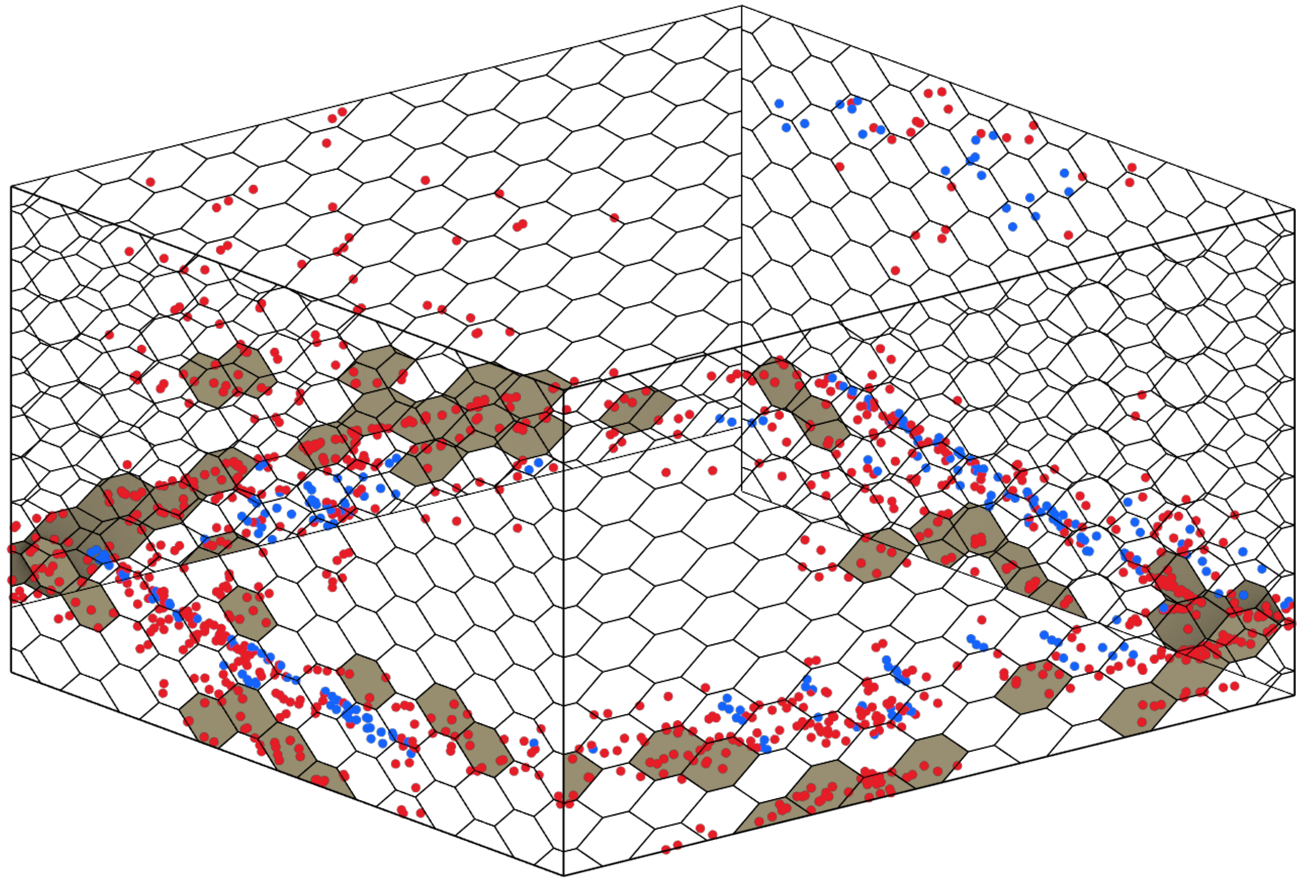


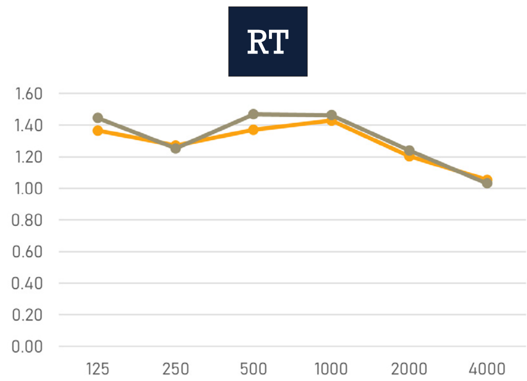


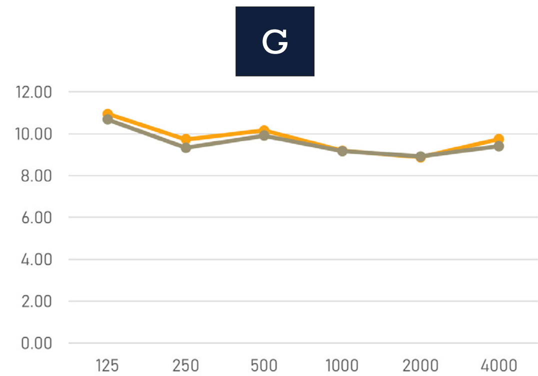




51 panels
29m^2



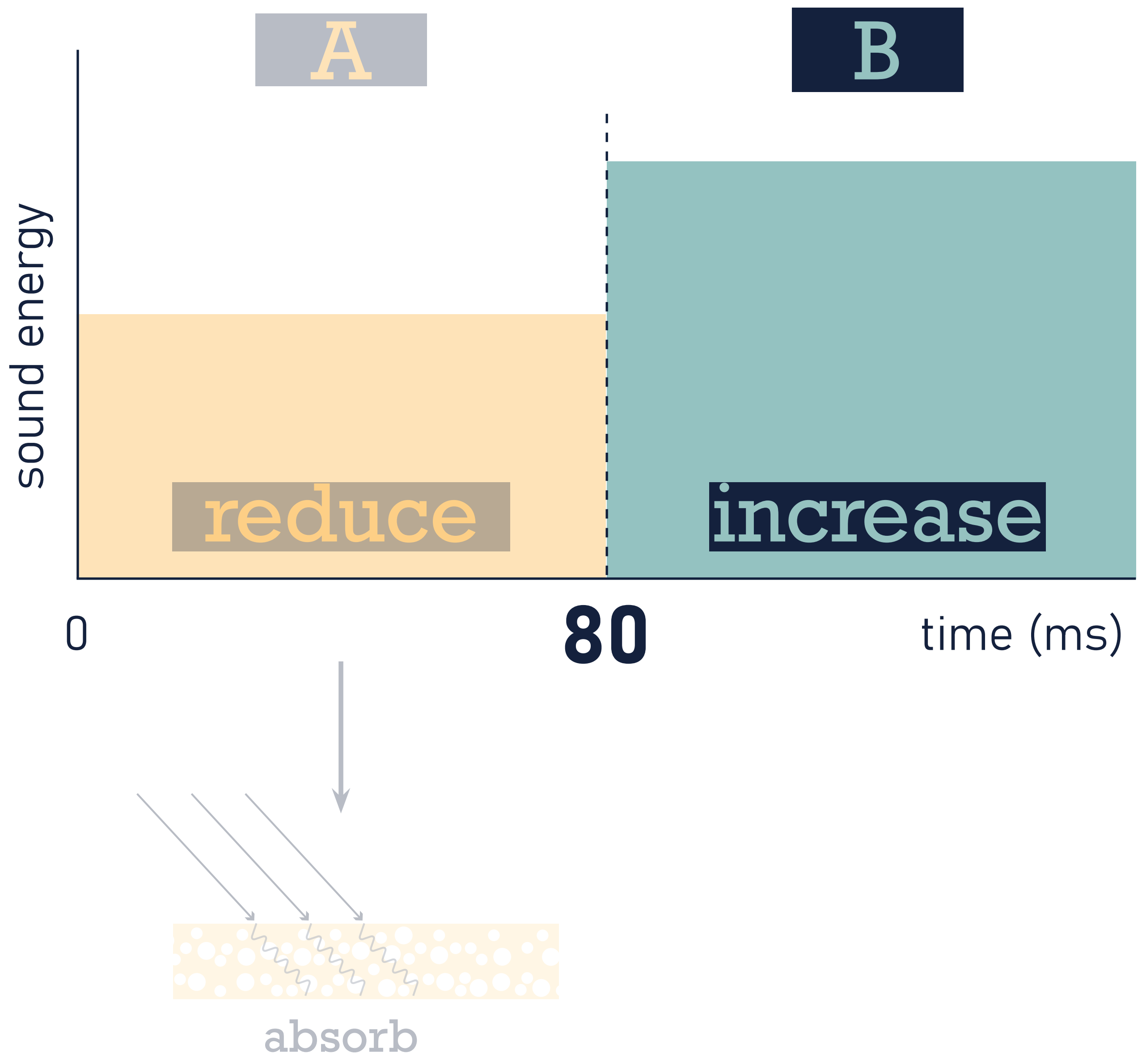




clarity index (definition)

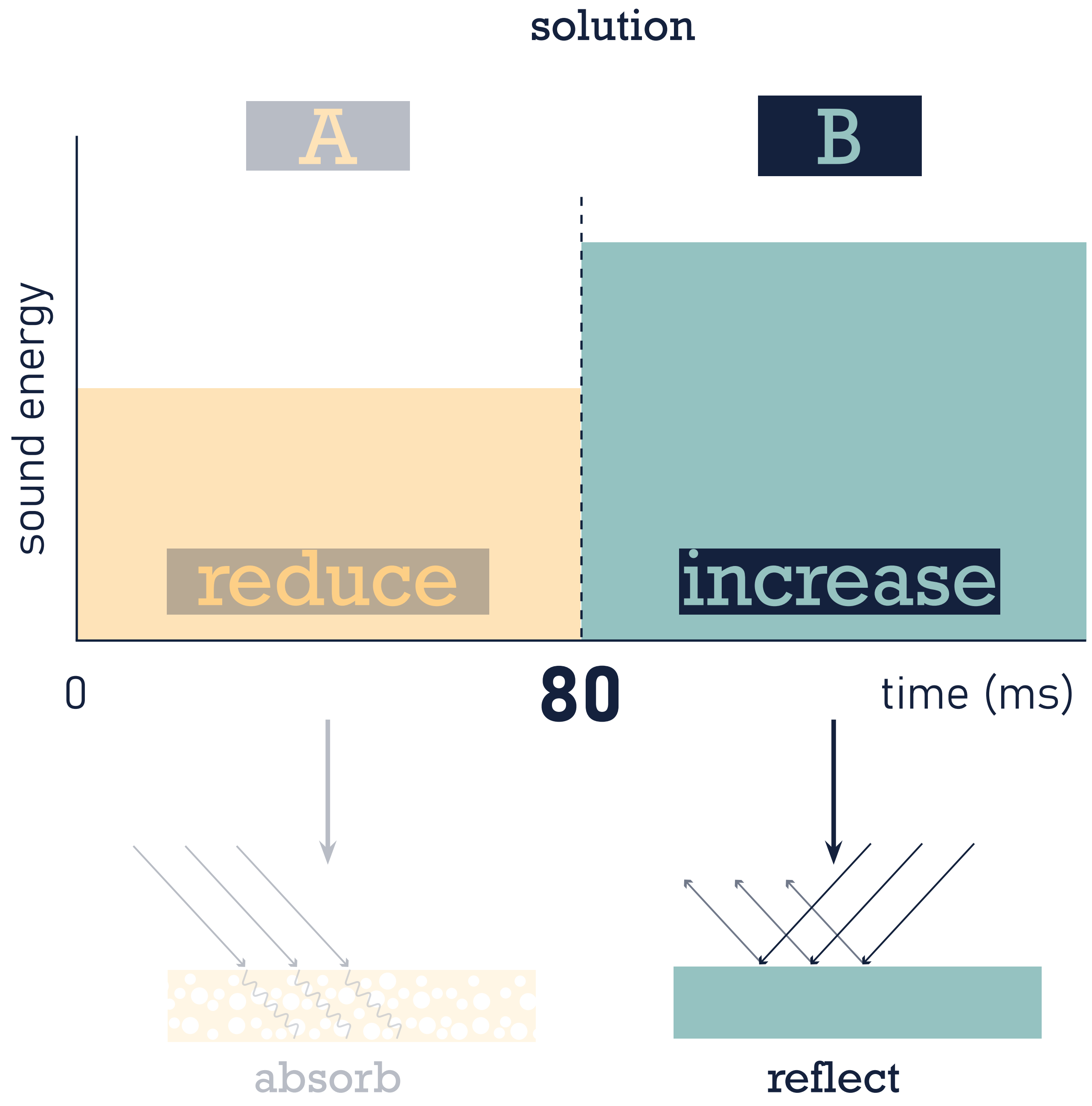
$$C80 = \frac{Early}{Late}$$

solution

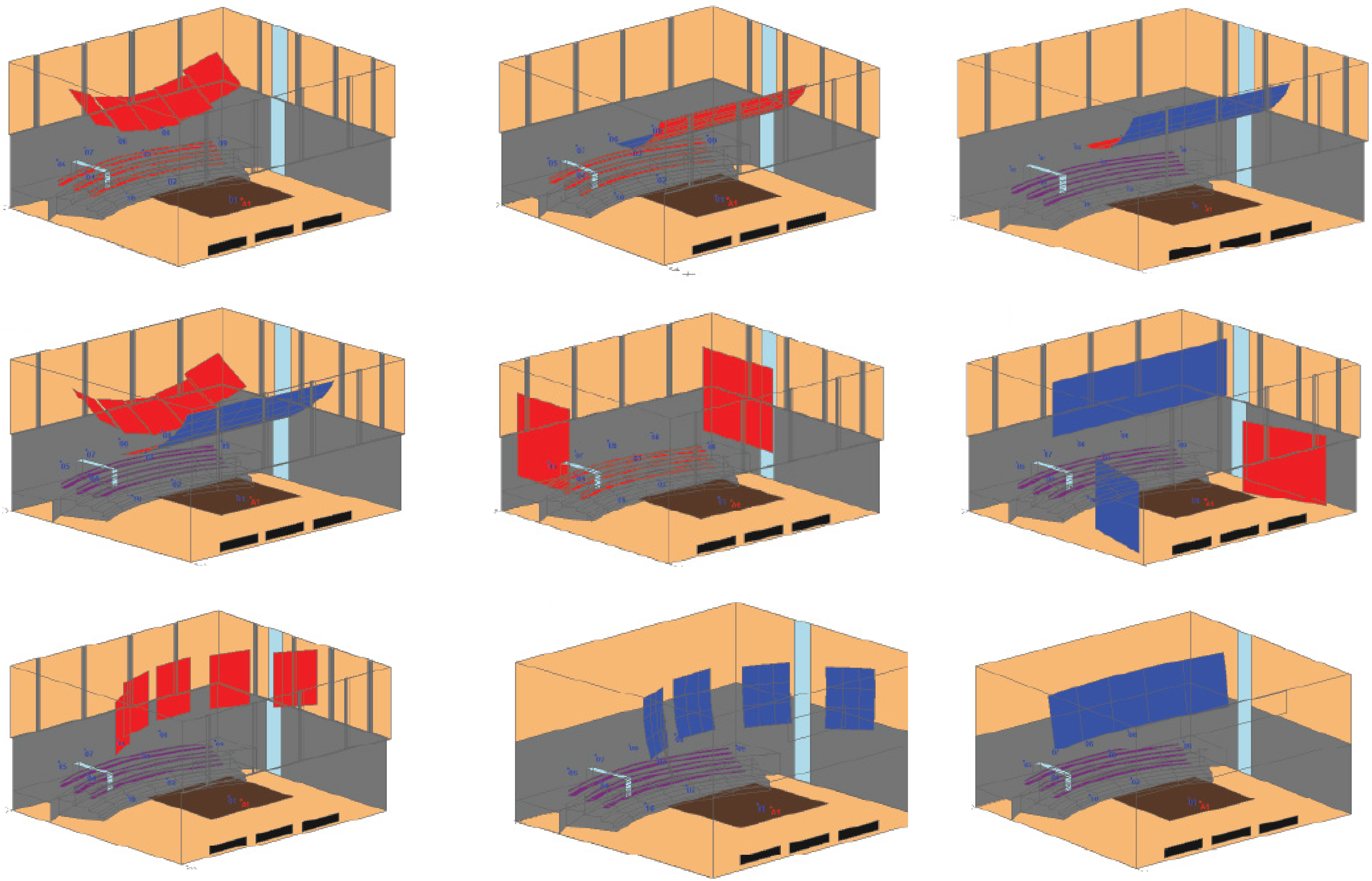


clarity index (definition)

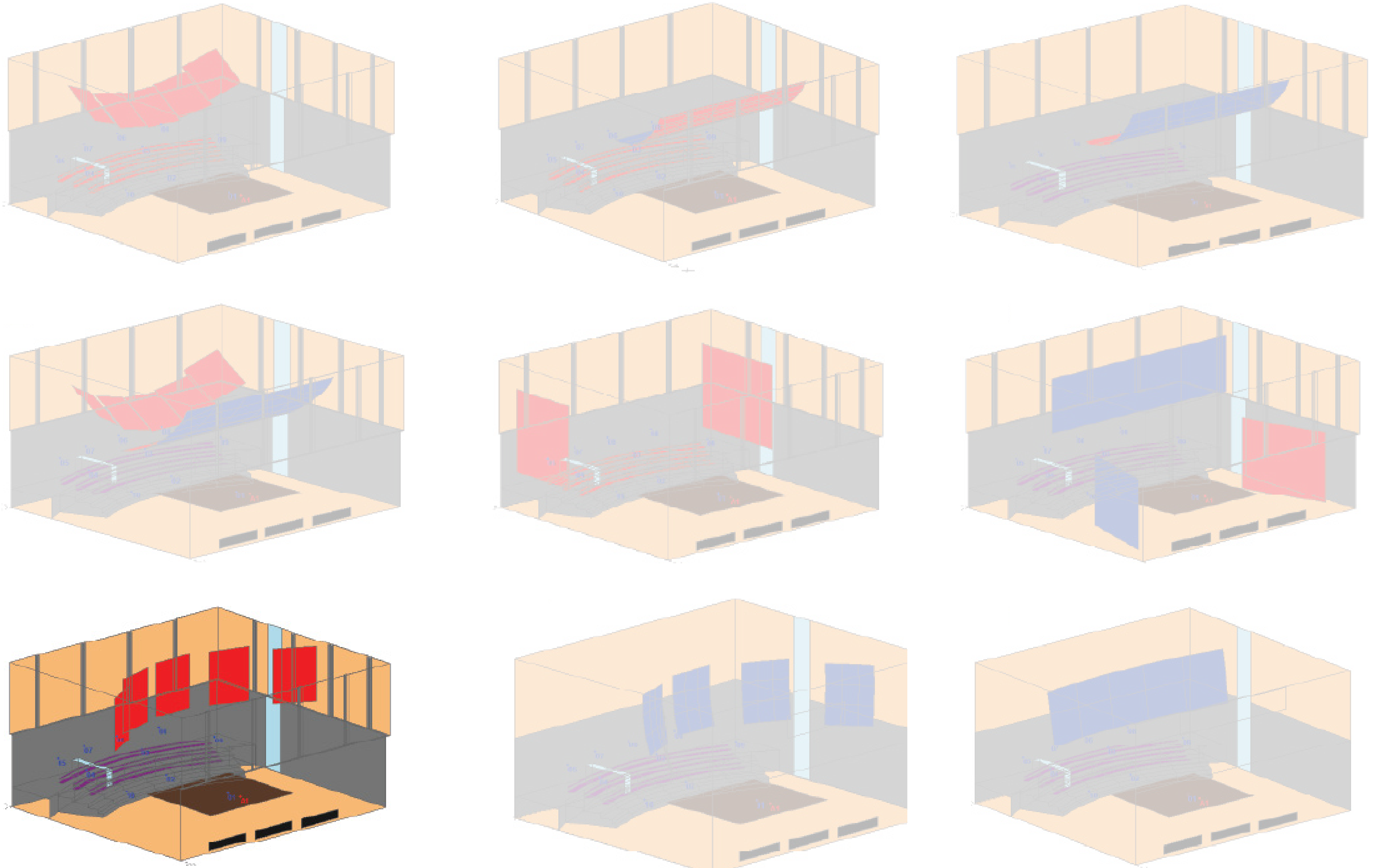
$$C80 = \frac{\text{Early}}{\text{Late}}$$



enhancing late sound



enhancing late sound

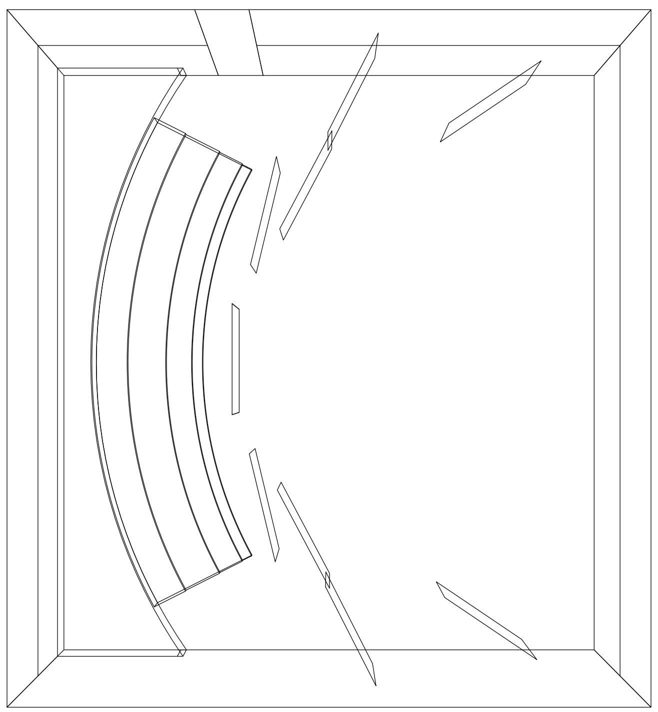


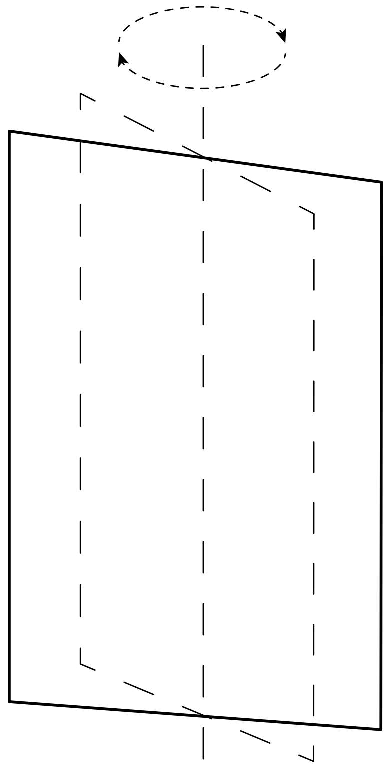
objective: **minimize the MSE of** C80

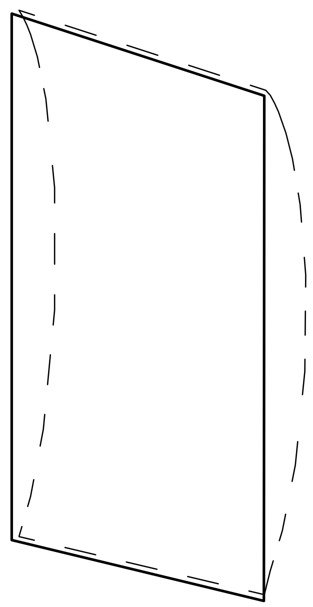
variable 1
rotation around the stage
(0-70°)

variable 2
rotation around its own z
axis (0-90°)

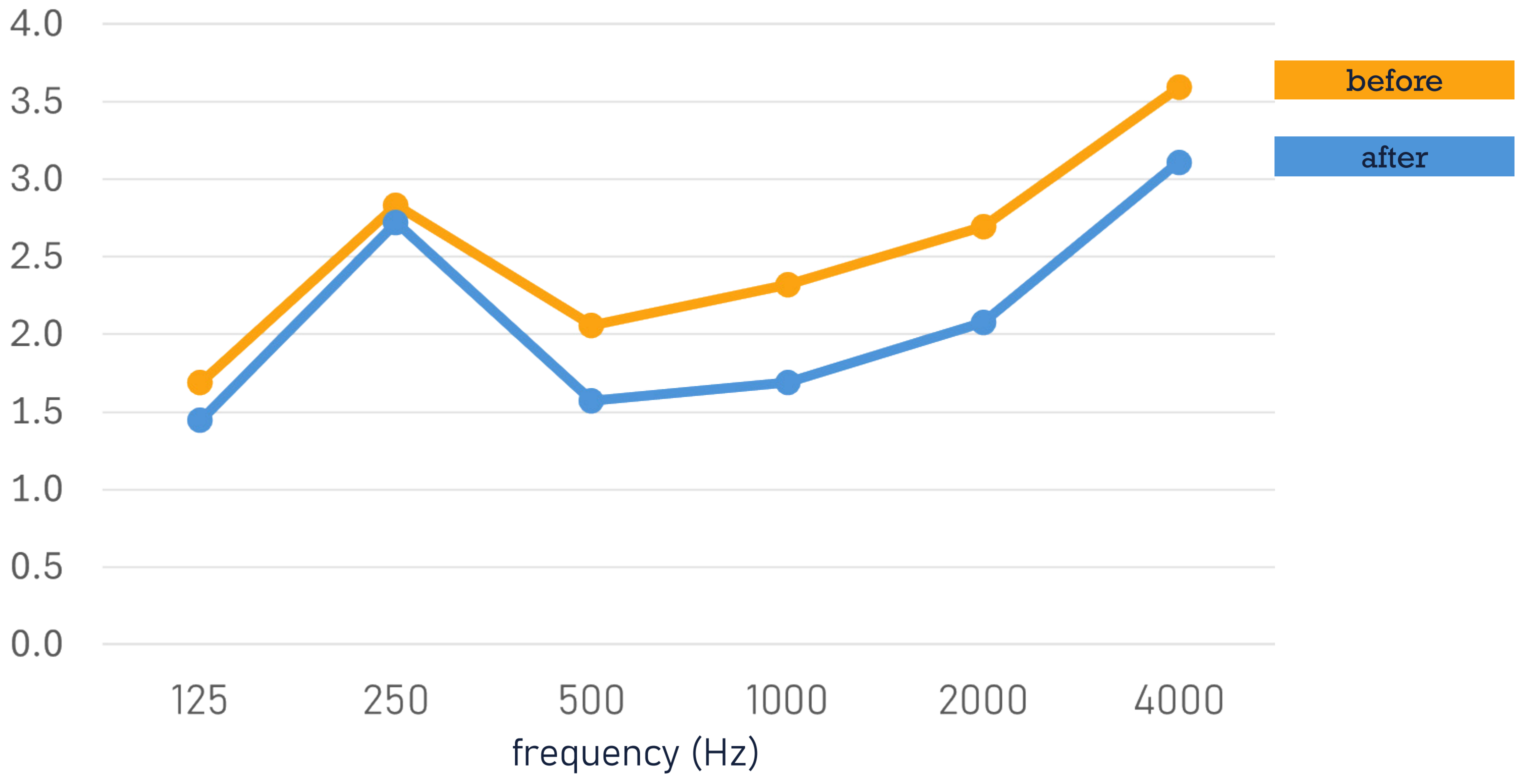
variable 3
bending degree
(-0.5 - 0.5 m)



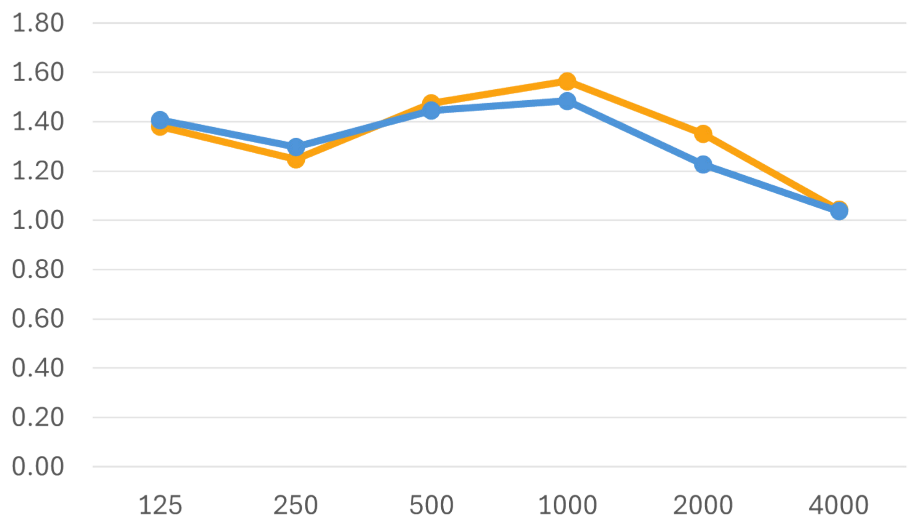




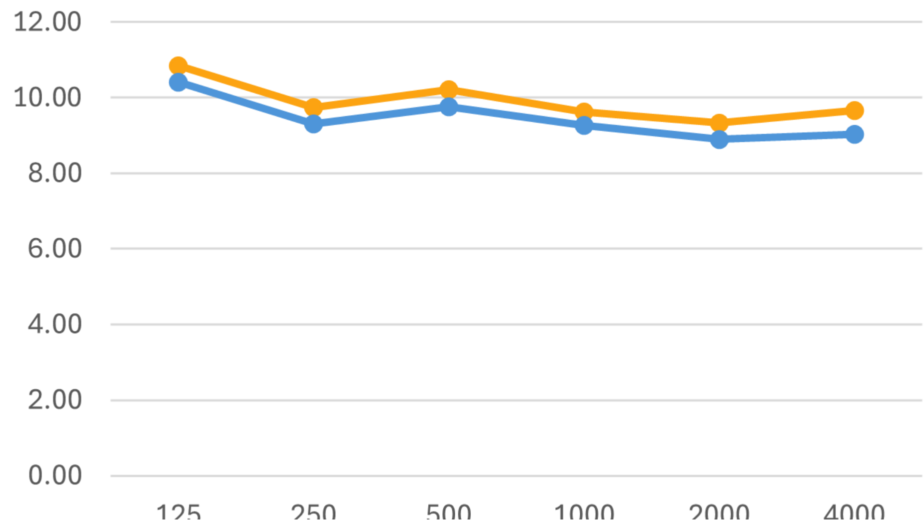
C80


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
before
after
125
250
500
1000
2000
4000
frequency (Hz)

RT

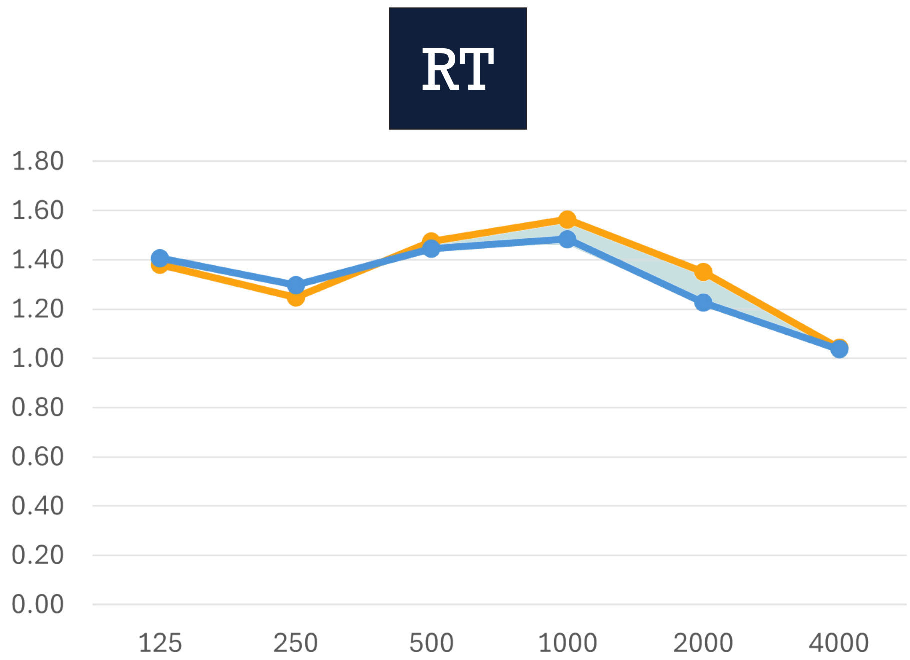

1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
125
250
500
1000
2000
4000

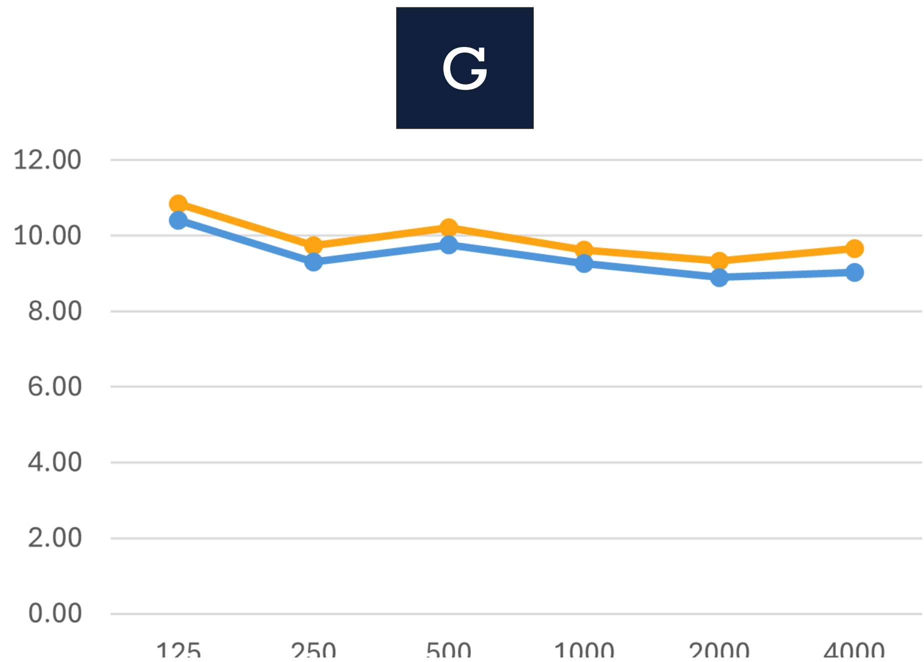
G

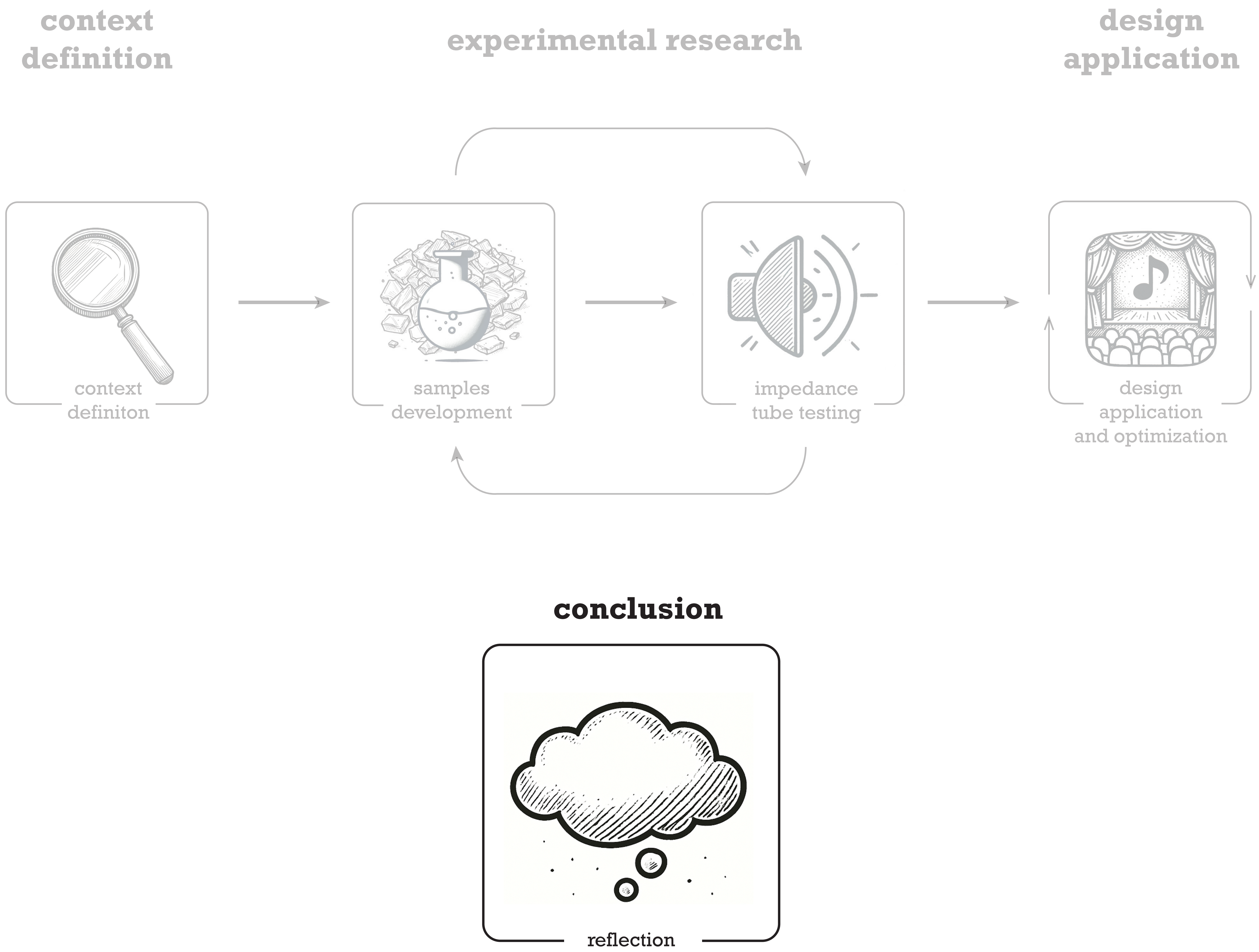

12.00
10.00
8.00
6.00
4.00
2.00
0.00

enhancing late sound

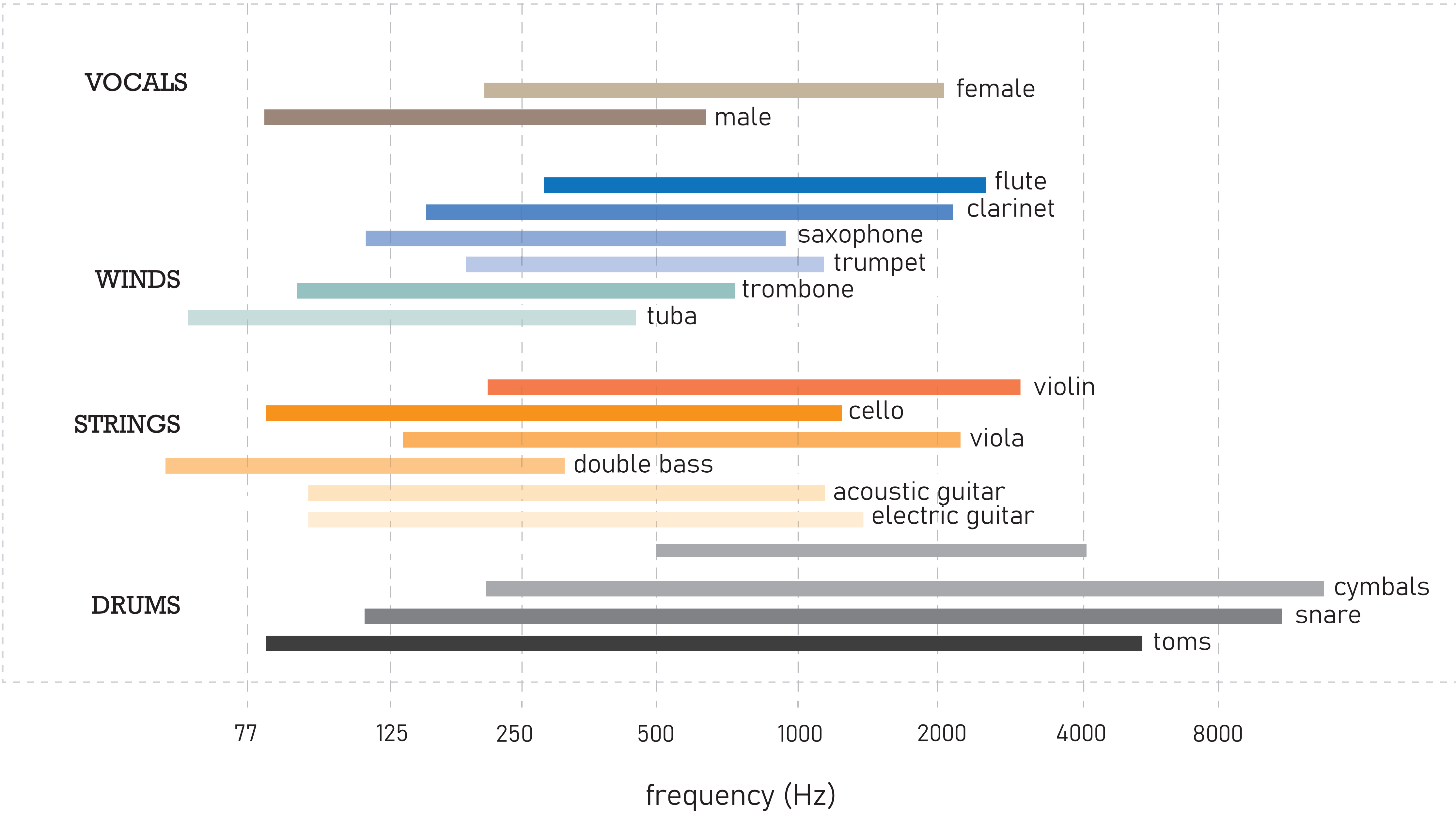
optimization

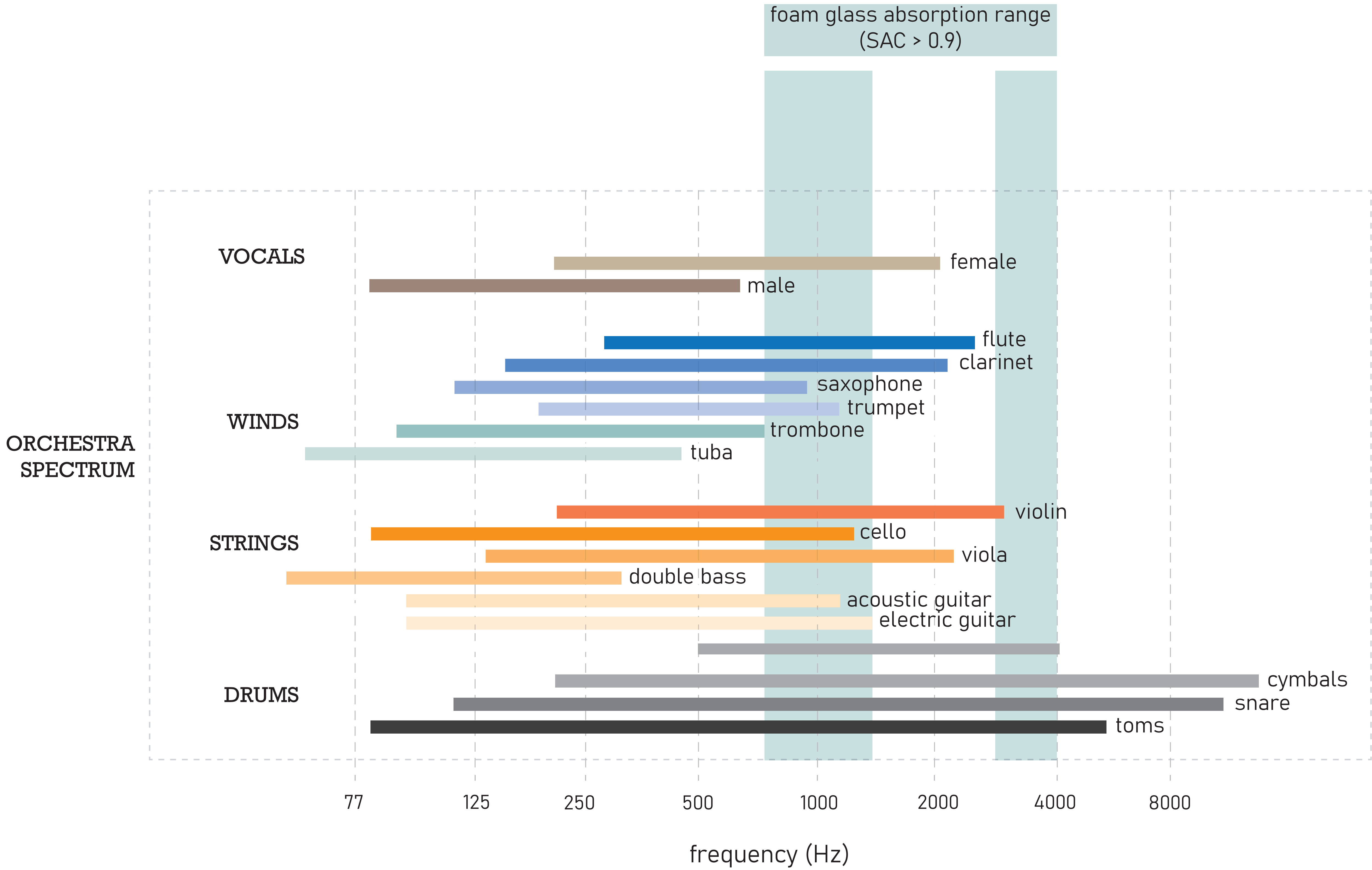


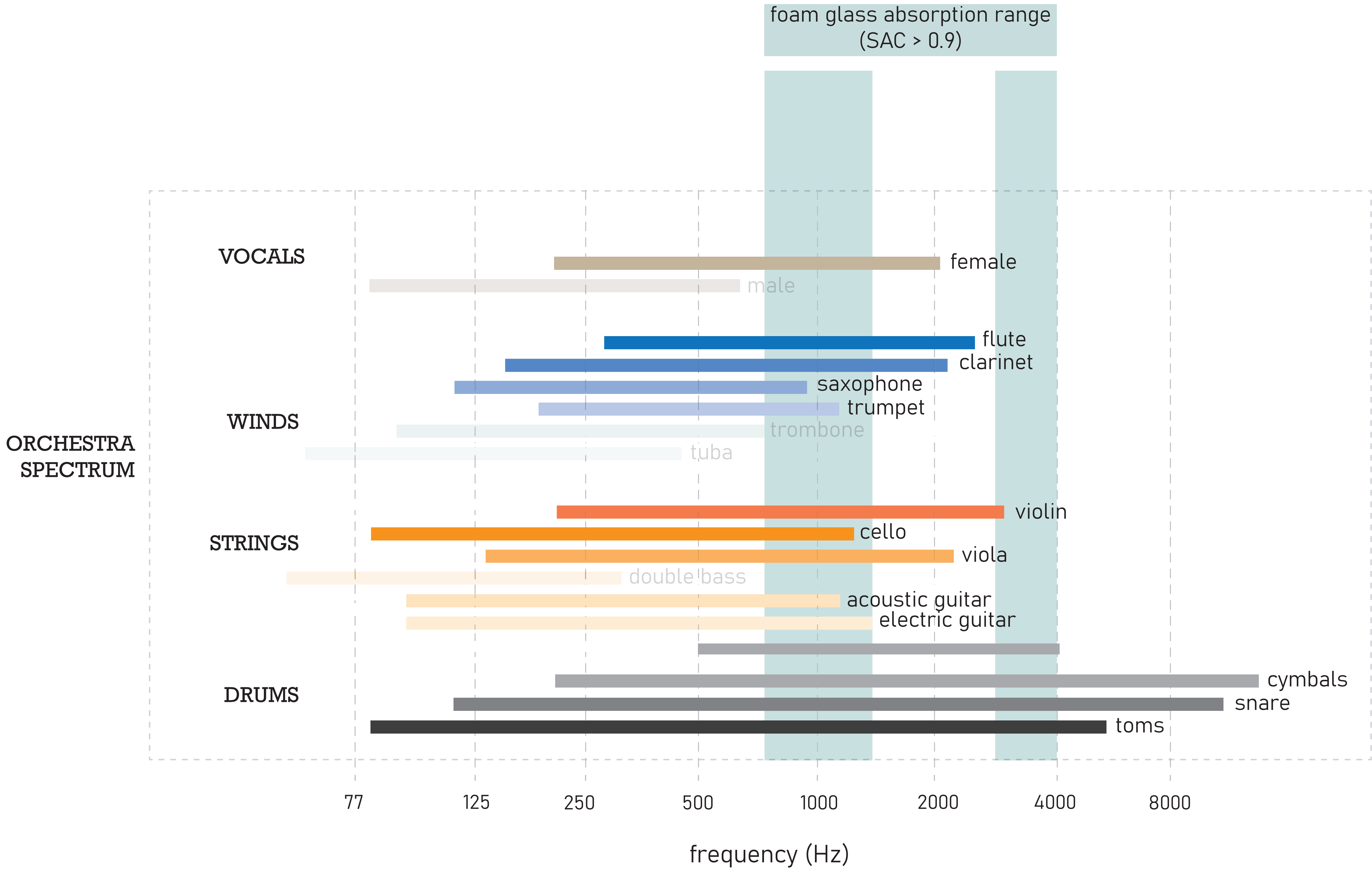


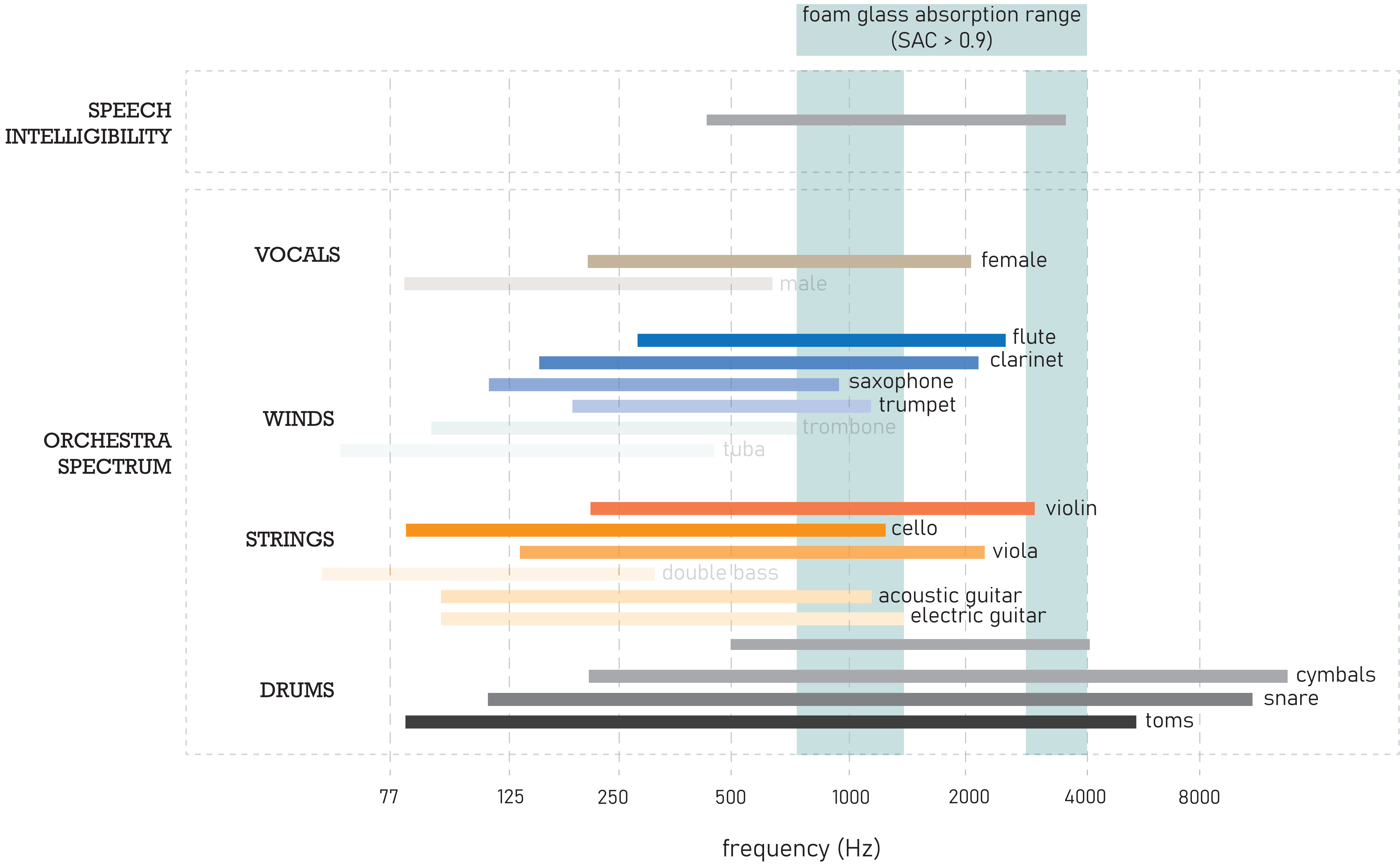

context
definition
experimental research
design
application
context
definiton
samples
development
impedance
tube testing
design
application
and optimization
conclusion
reflection

ORCHESTRA SPECTRUM




foam glass absorption range
(SAC > 0.9)
ORCHESTRA
SPECTRUM
VOCALS
female
male
WINDS
flute
clarinet
saxophone
trumpet
trombone
tuba
STRINGS
violin
cello
viola
double bass
acoustic guitar
electric guitar
DRUMS
cymbals
snare
toms
77
125
250
500
1000
2000
4000
8000
frequency (Hz)


foam glass absorption range
(SAC > 0.9)
ORCHESTRA
SPECTRUM
VOCALS
female
male
WINDS
flute
clarinet
saxophone
trumpet
trombone
tuba
STRINGS
violin
cello
viola
double bass
acoustic guitar
electric guitar
DRUMS
cymbals
snare
toms
77
125
250
500
1000
2000
4000
8000
frequency (Hz)


foam glass absorption range
(SAC > 0.9)
SPEECH INTELLIGIBILITY
ORCHESTRA SPECTRUM
VOCALS
female
male
WINDS
flute
clarinet
saxophone
trumpet
trombone
tuba
STRINGS
violin
cello
viola
double bass
acoustic guitar
electric guitar
DRUMS
cymbals
snare
toms
77
125
250
500
1000
2000
4000
8000
frequency (Hz)

What are the potential and limitations of developing a porous material from glass waste to produce acoustic panels for architectural space?

What are the potential and limitations of developing a porous material from glass waste to produce acoustic panels for architectural space?

limitations

- randomness of foaming reaction
- manufacturing challenges
- low (no) absorption in low frequencies

What are the potential and limitations of developing a porous material from glass waste to produce acoustic panels for architectural space?

limitations

- randomness of foaming reaction
- manufacturing challenges
- low (no) absorption in low frequencies

potential

- excellent acoustic performance in mid-high frequencies
- circular product
- architectural adaptability

THANK YOU!

references

Visuals were generated using OpenAI, ChatGPT if not specified differently.

[1] Bernardo, E., Cedro, R., Florean, M., & Hreglich, S. (2007). Reutilization and stabilization of wastes by the production of glass foams. Ceramics International, 33(5), 963–968. https://doi.org/10.1016/j.ceramint.2006.02.010

[2] Bristogianni, T., Oikonomopoulou, F., Justino de Lima, C., Veer, F., & Nijsse, R. (2018). Structural cast glass components manufactured from waste glass: Diverting everyday discarded glass from the landfill to the building industry. Heron, 63(1/2), 57-102. Article 4.

[3] Bristogianni, T., & Oikonomopoulou, F. (2022). Glass up-casting: A review on the current challenges in glass recycling and a novel approach for recycling "as-is" glass waste into volumetric glass components. Glass Structures & Engineering, 8, 255–302. https://doi.org/10.1007/s40940-022-00206-9

[4] Buratti, C., Belloni, E., Lascaro, E., Lopez, G. A., & Ricciardi, P. (2016). Sustainable panels with recycled materials for building applications: Environmental and acoustic characterization. Energy Procedia, 101, 972–979. https://doi.org/10.1016/j.egypro.2016.11.123

[5] Cai, L., Tian, J., Feng, K., Liu, Y., & Jiang, Q. (2023). Sound absorption model of foam glass-ceramics based on microstructure. Journal of Non-Crystalline Solids, 604, 122136. https://doi.org/10.1016/j.jnoncrysol.2023.122136

[6] Cho, H., Choi, C., Kim, J., Choi, D., & Lee, S. W. (2005). Sound absorbing properties of foamed glasses. Materials Science Forum, 486-487, 578–581. https://doi.org/10.4028/www.scientific.net/MSF.486-487.578

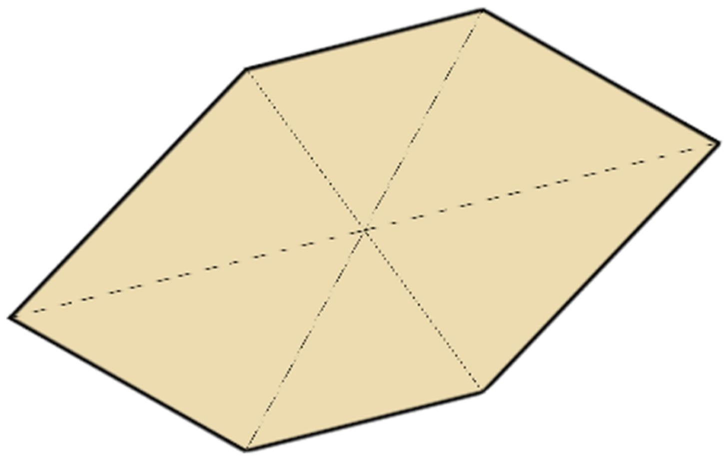
[7] DeBrincat, G., & Babic, E. (2018). Re-thinking the life-cycle of architectural glass: Construction flat glass recycling viability study & value report. ARUP.

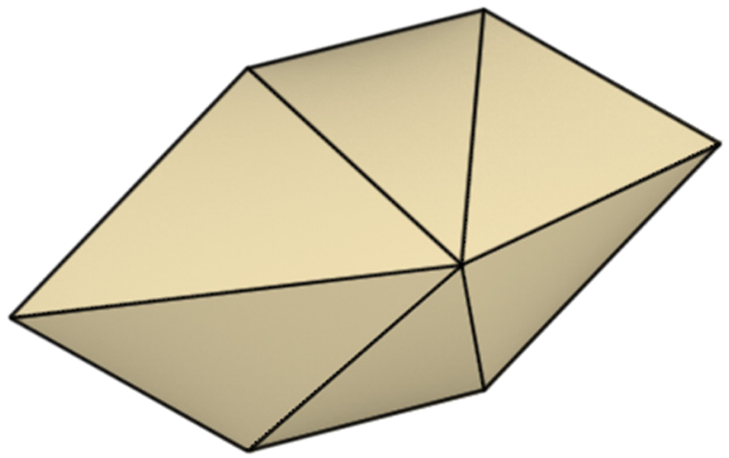
[8] Giassia G. (2022). Bio-host glass: A recycled porous glass foam, developed for bioreceptive applications in the urban environment. Delft University of Technology.

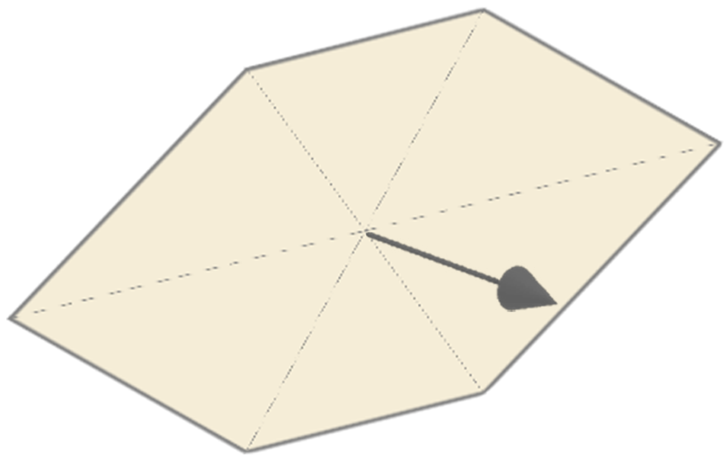
[9] Hesky, D., Aneziris, C. G., Groß, U., & Horn, A. (2015). Water and waterglass mixtures for foam glass production. Ceramics International, 41(10), 12604–12613. https://doi.org/10.1016/j.ceramint.2015.06.088

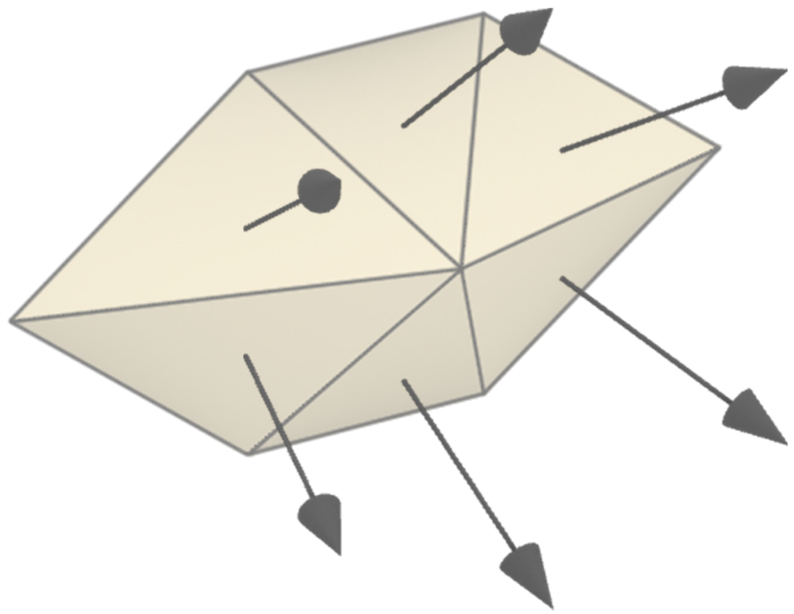
[10] Setaki, F., Tian, F., Turrin, M., Tenpierik, M., Nijs, L., & Van Timmeren, A. (2023). 3D-printed sound absorbers: Compact and customisable at broadband frequencies. Architecture, Structures and Construction, 3(2), 205–215. https://doi.org/10.1007/s44150-023-00086-9

[11] Souza, M. T., Maia, B. G. O., Teixeira, L. B., de Oliveira, K. G., Teixeira, A. H. B., & Novaes de Oliveira, A. P. (2017). Glass foams produced from glass bottles and eggshell wastes. Process Safety and Environmental Protection, 111, 60–64. https://doi.org/10.1016/j.psep.2017.06.011

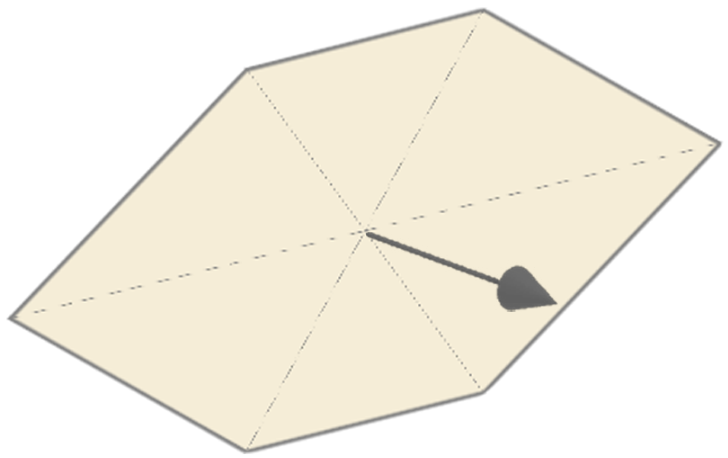


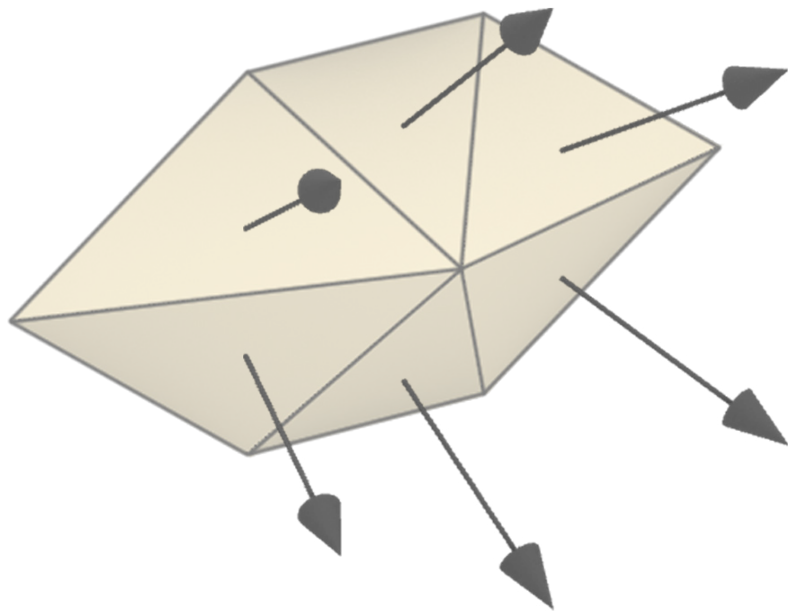


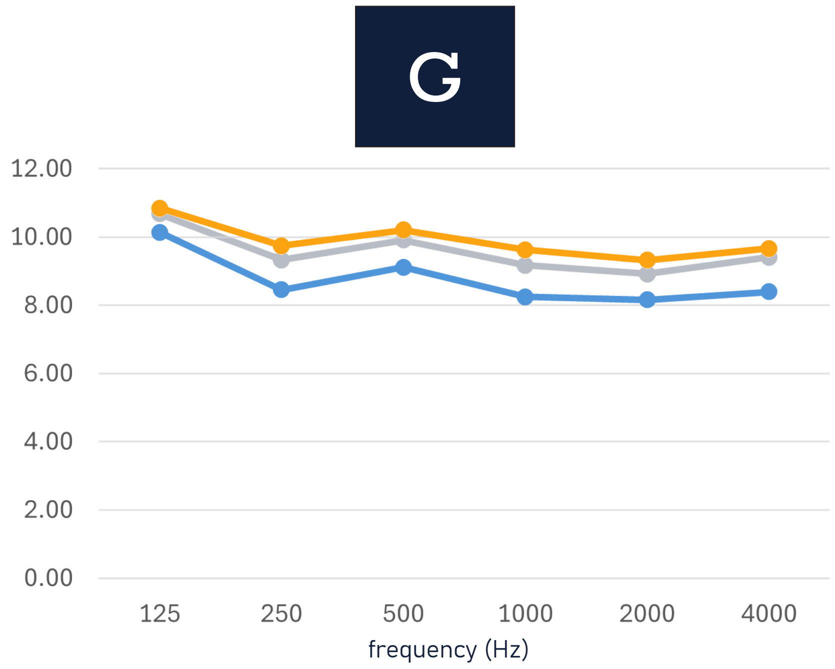


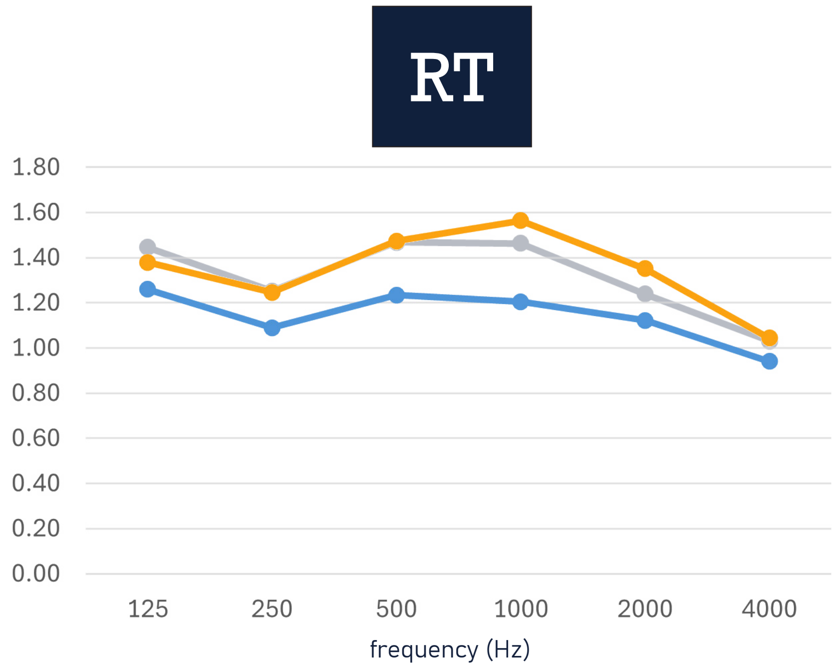


enhancing diffusion

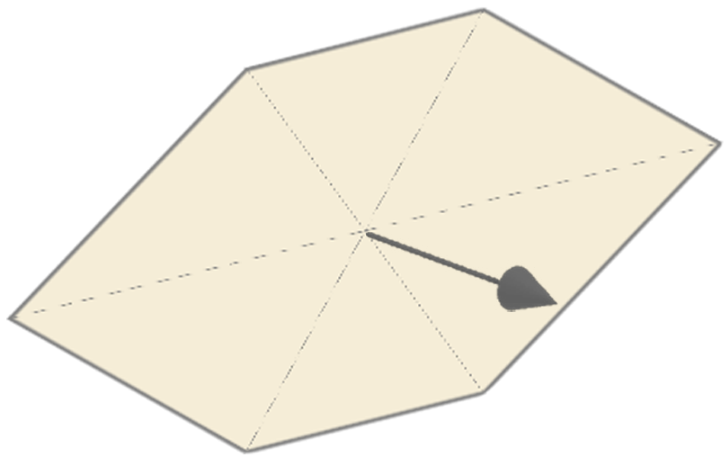


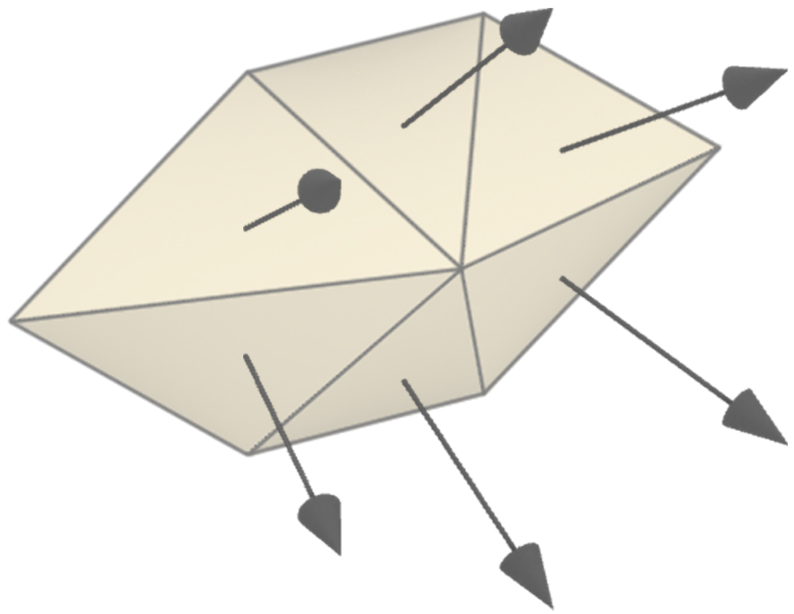


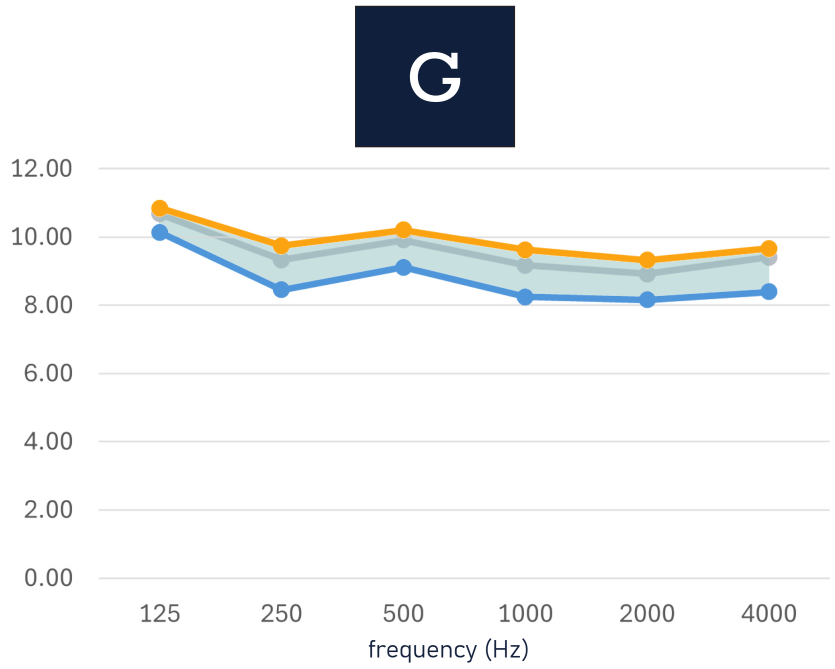


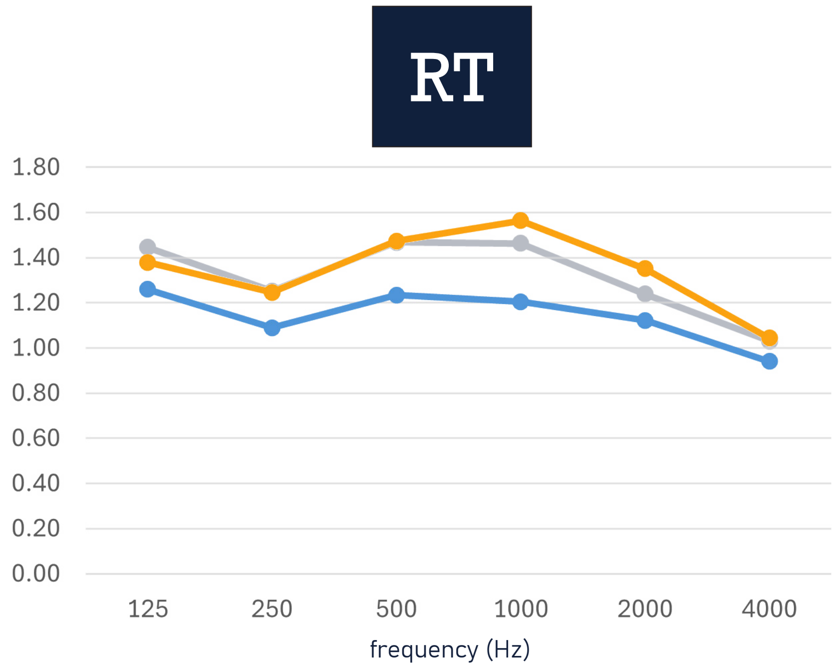


enhancing diffusion

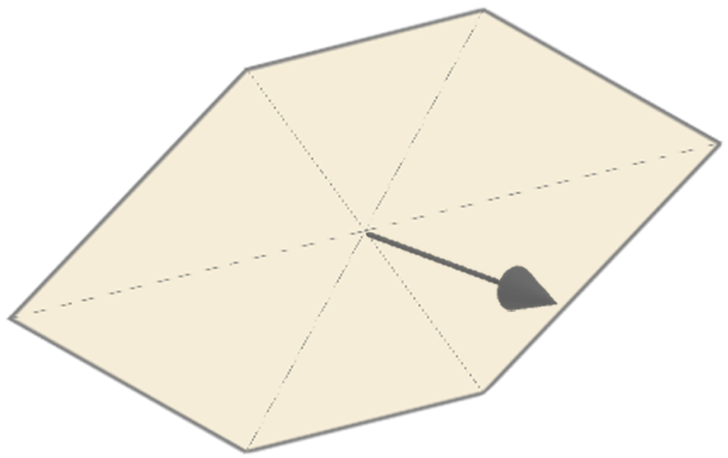


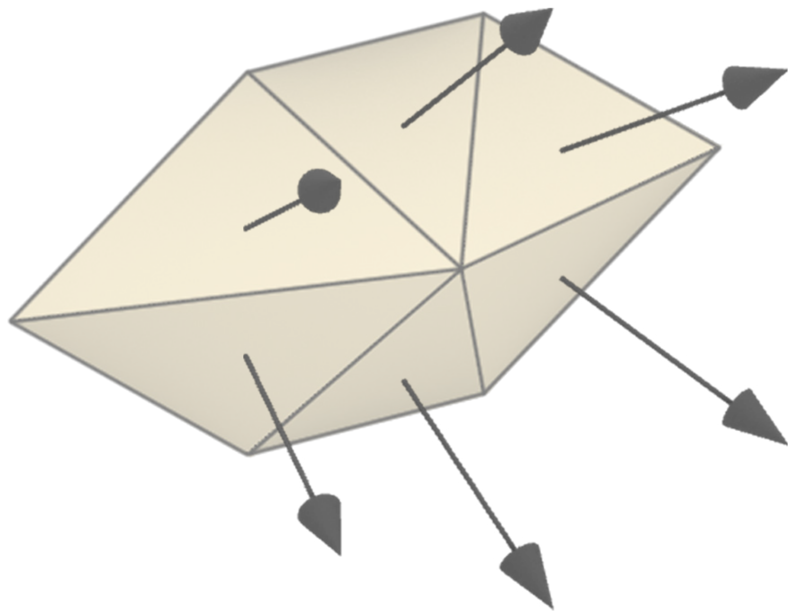




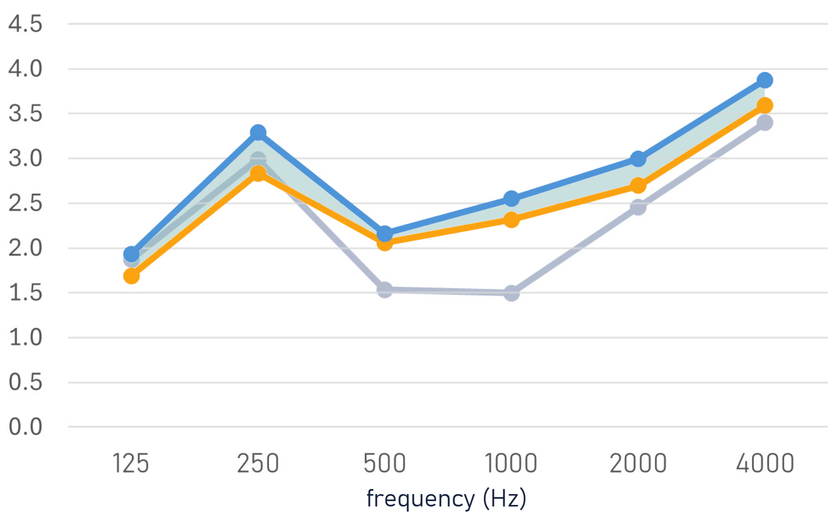


enhancing diffusion

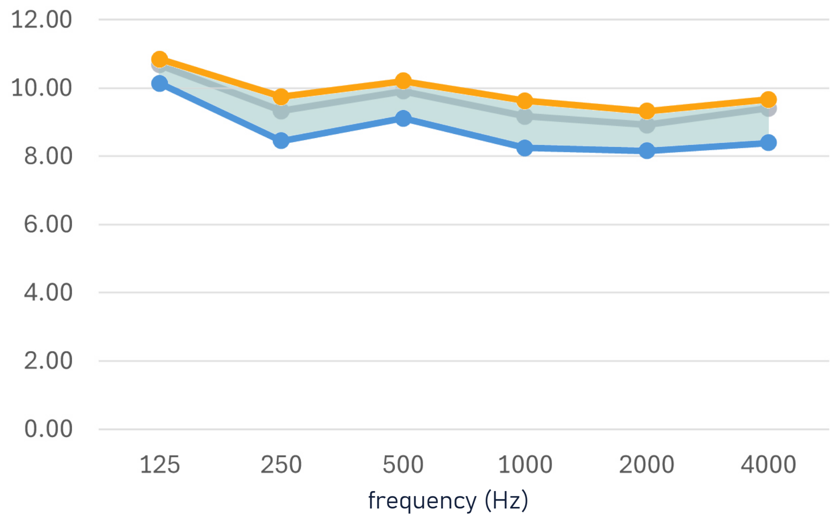




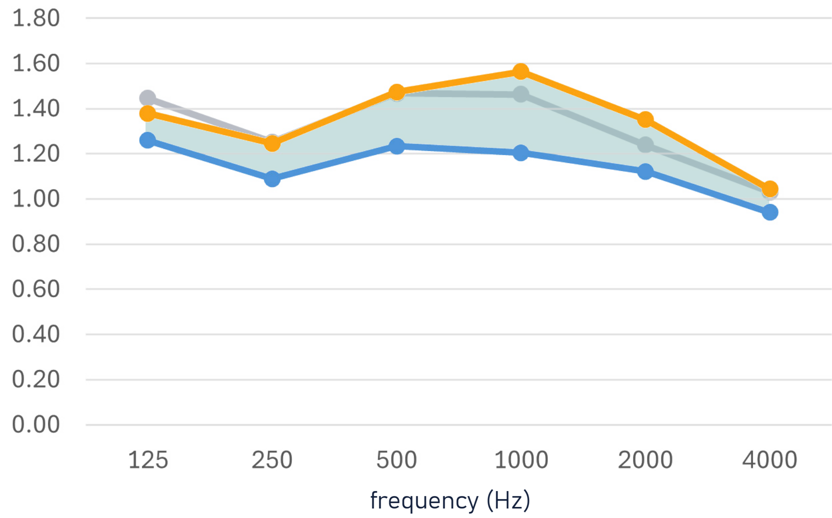
C80



G

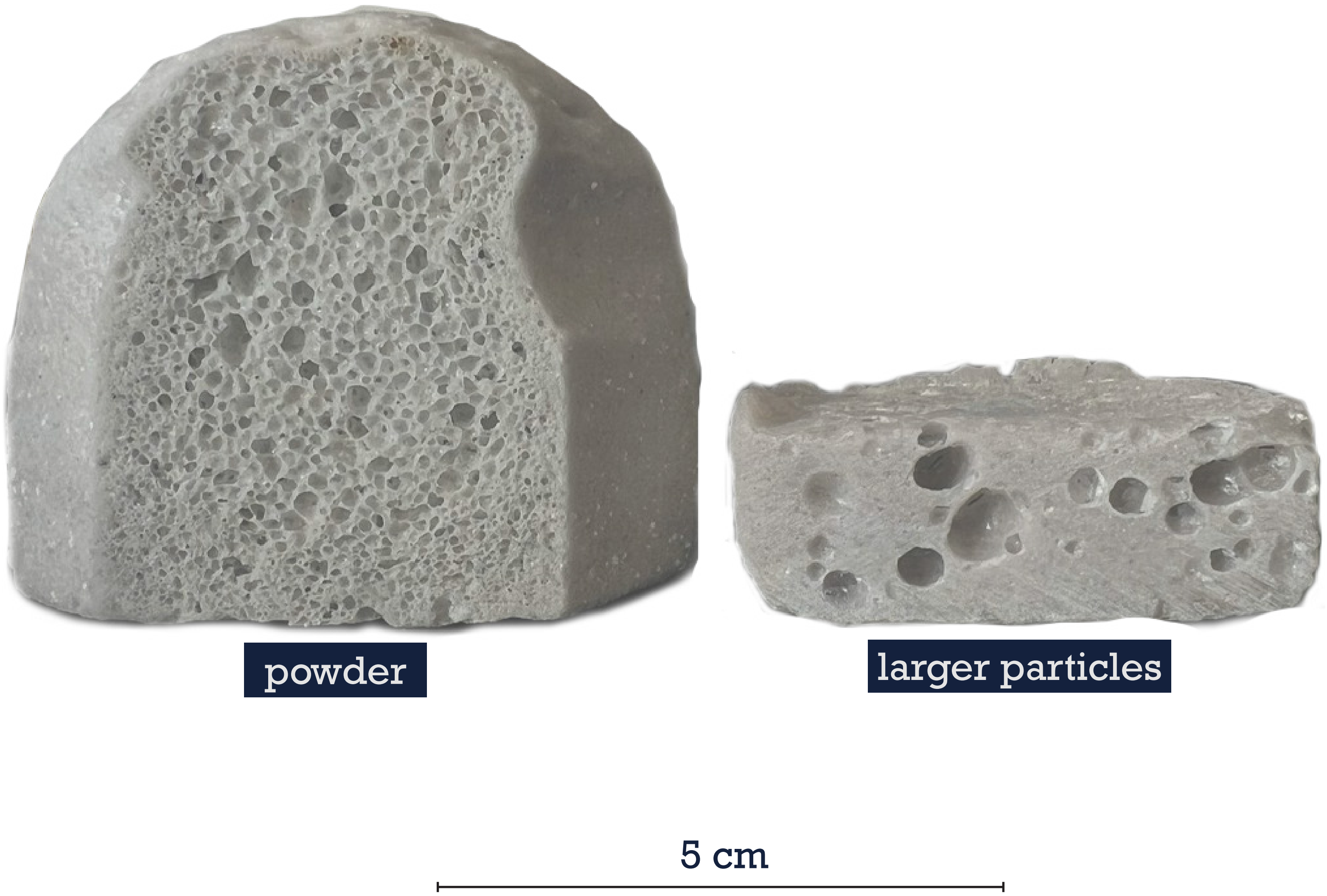


RT

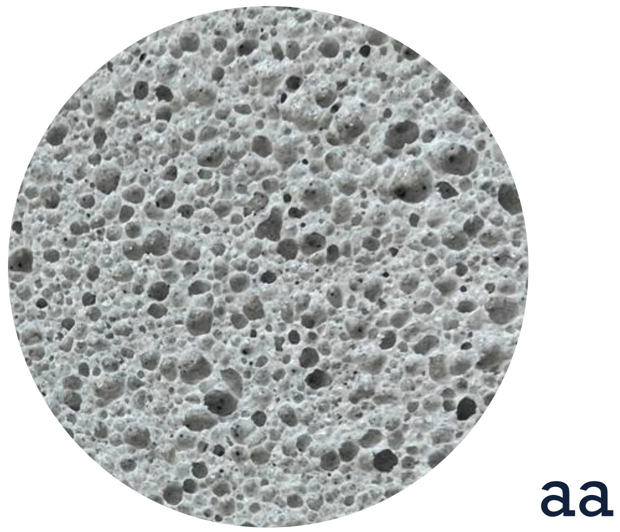


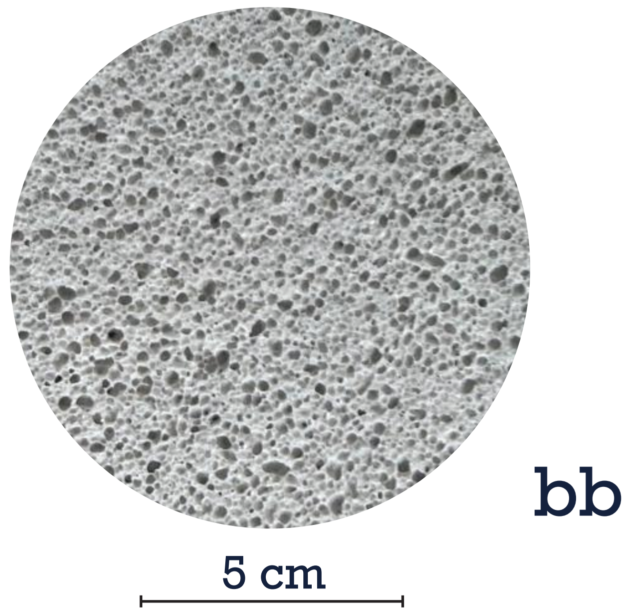
mixing different foaming agent concentrations

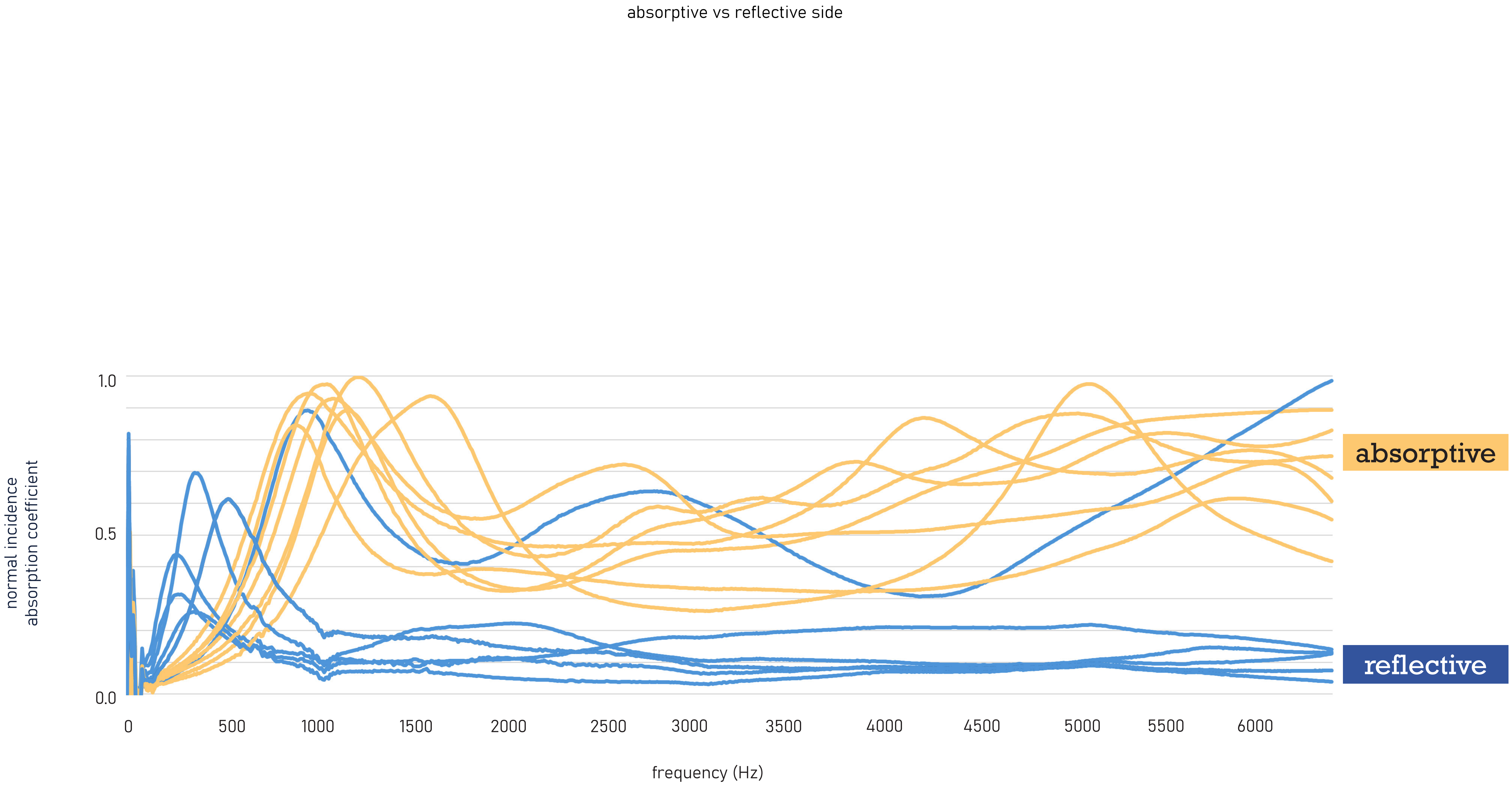
foaming agent particle size



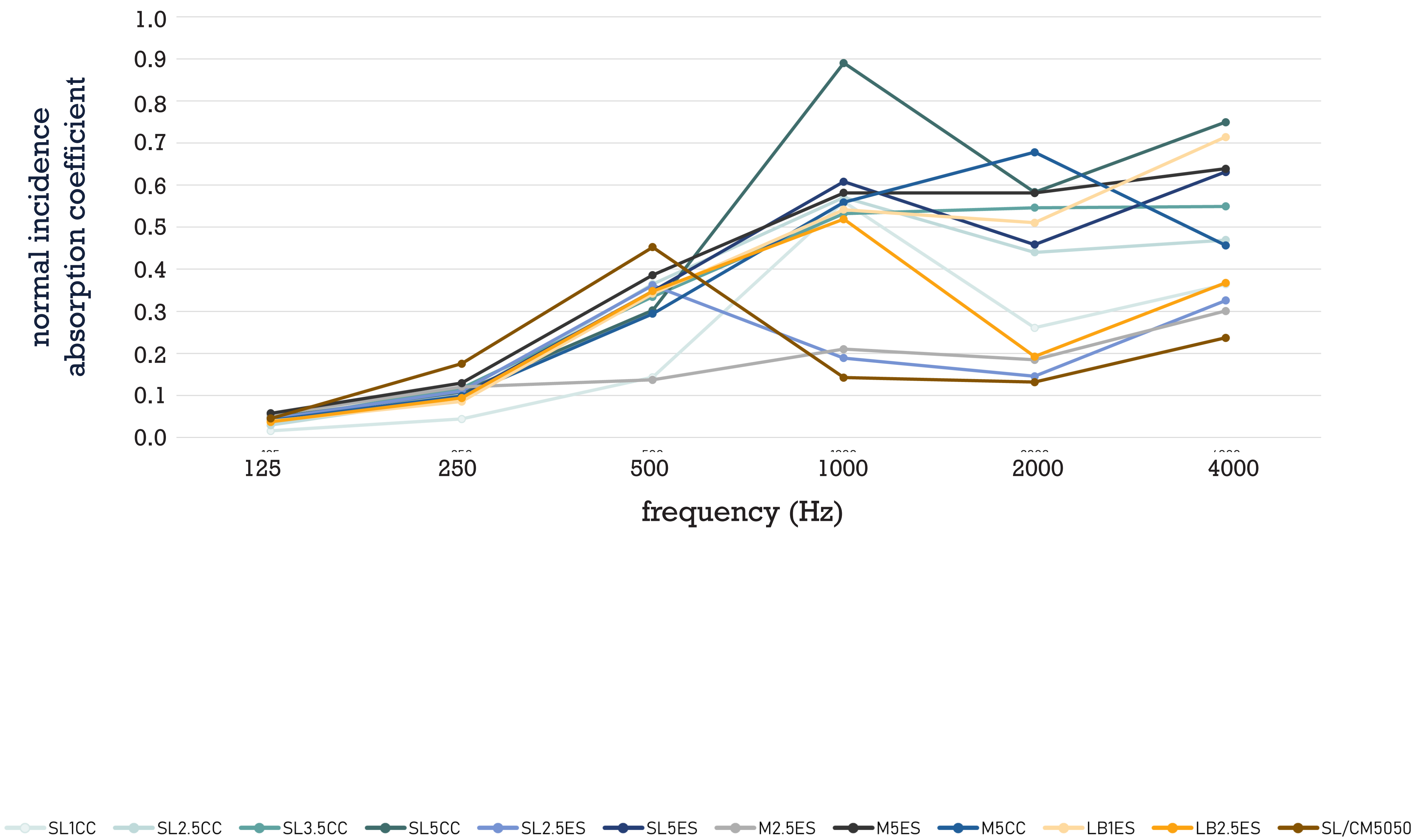
gradient porosity within one sample

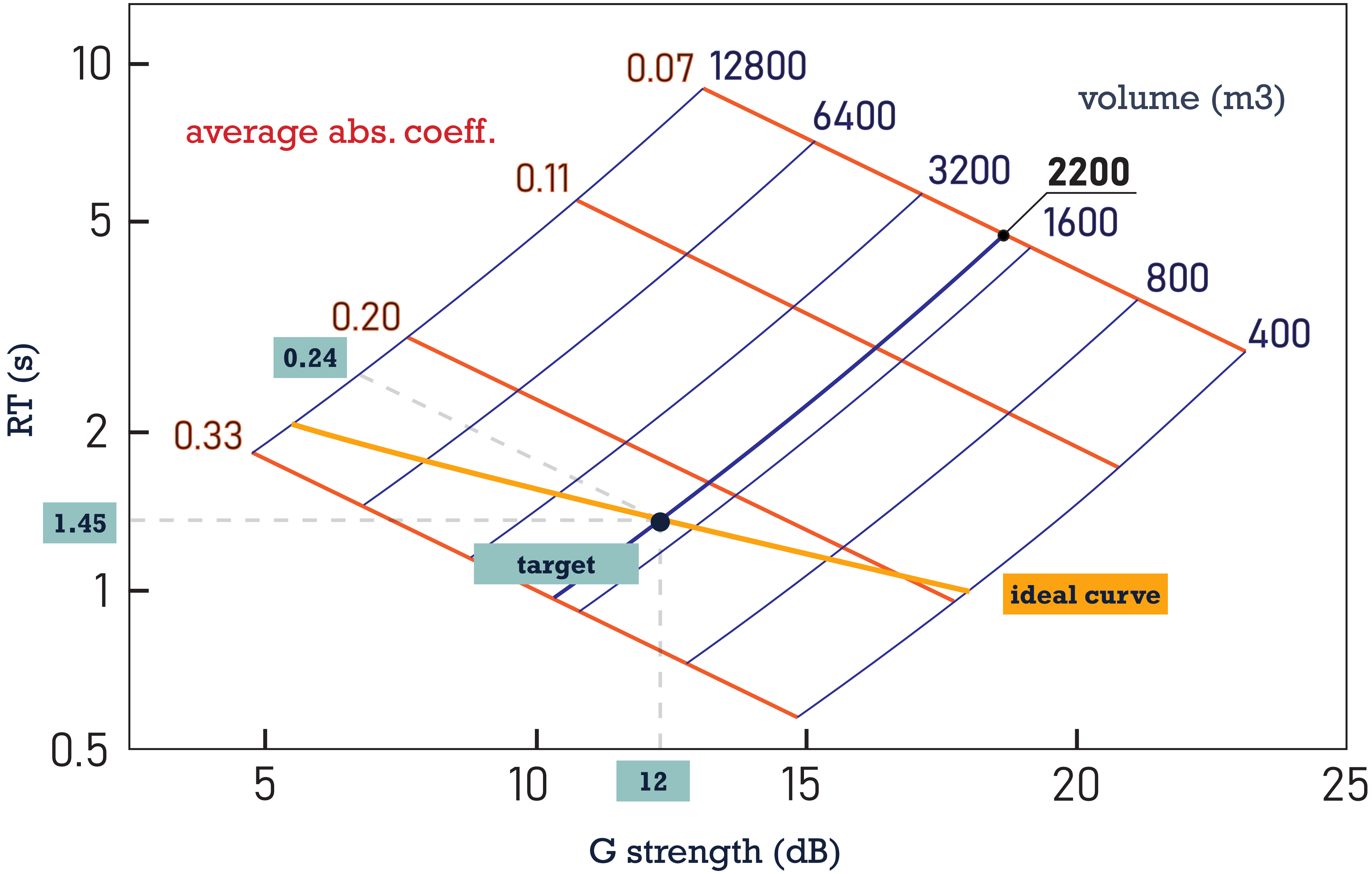





absorptive vs reflective side
1.0
0.5
0.0
normal incidence
absorption coefficient
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
frequency (Hz)
absorptive
reflective

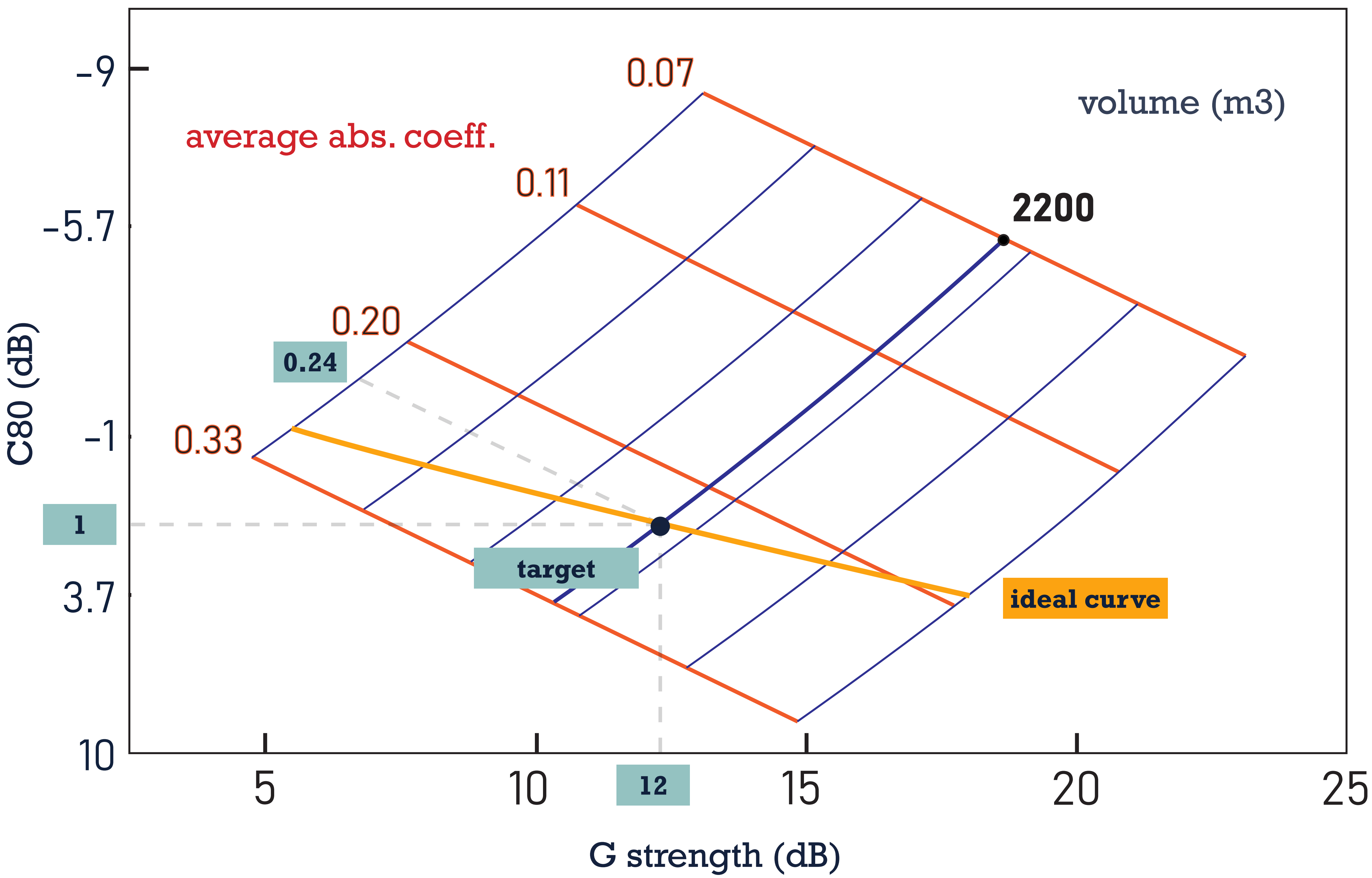
octave bands



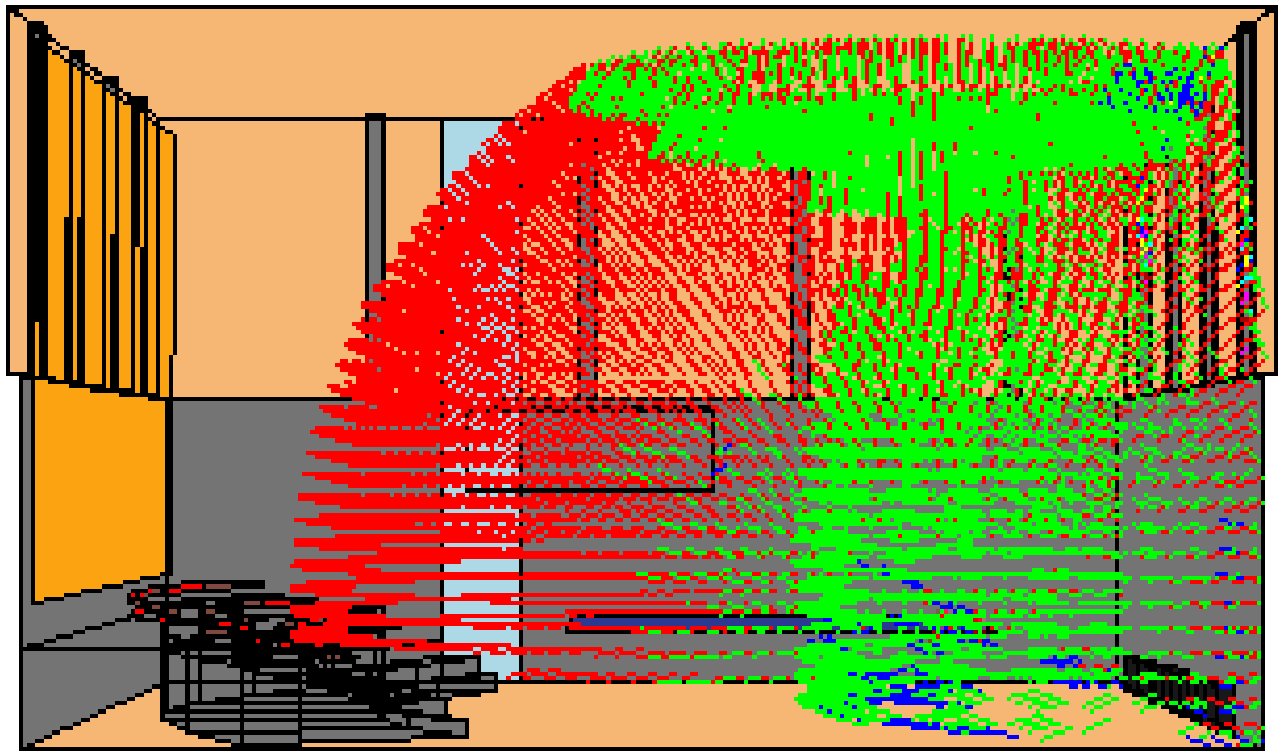


10
5
2
1
0.5
RT (s)
average abs. coeff.
0.07
0.11
0.20
0.33
0.24
1.45
12800
6400
3200
2200
1600
800
400
volume (m3)
target
ideal curve
5
10
12
15
20
25
G strength (dB)

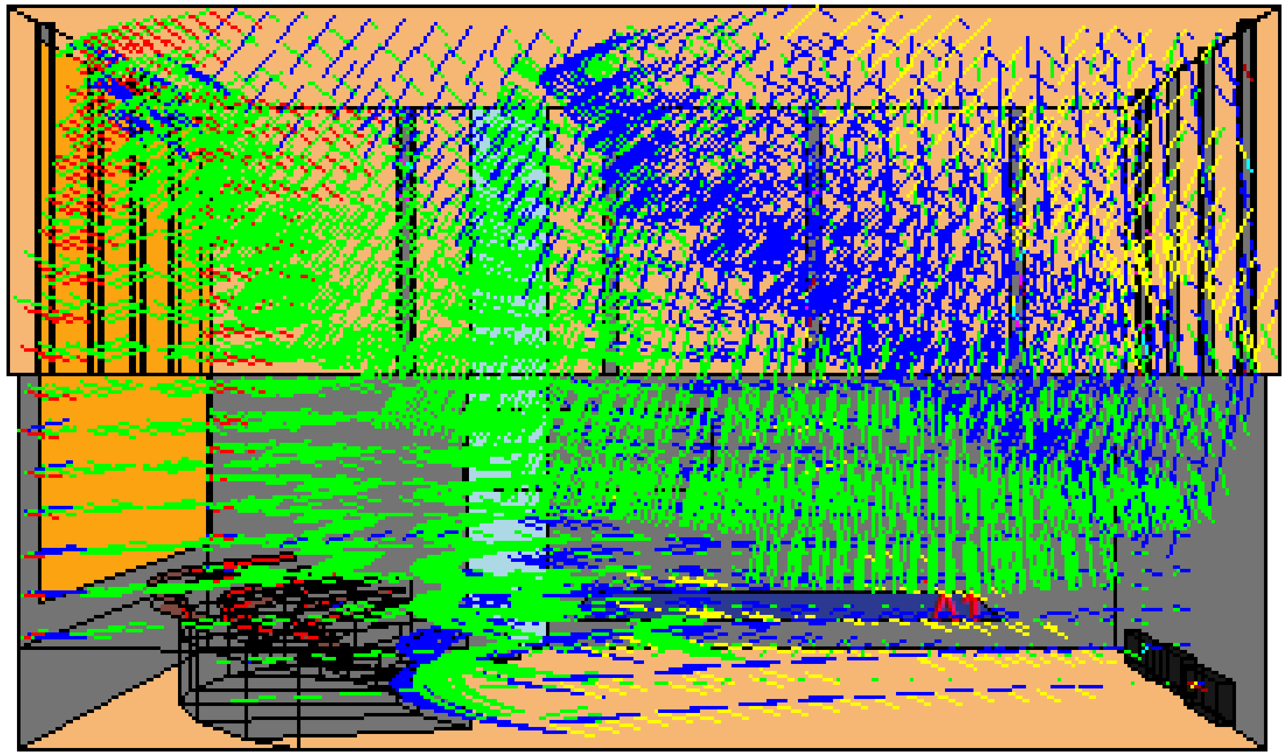
C80 - G diagram



24 ms



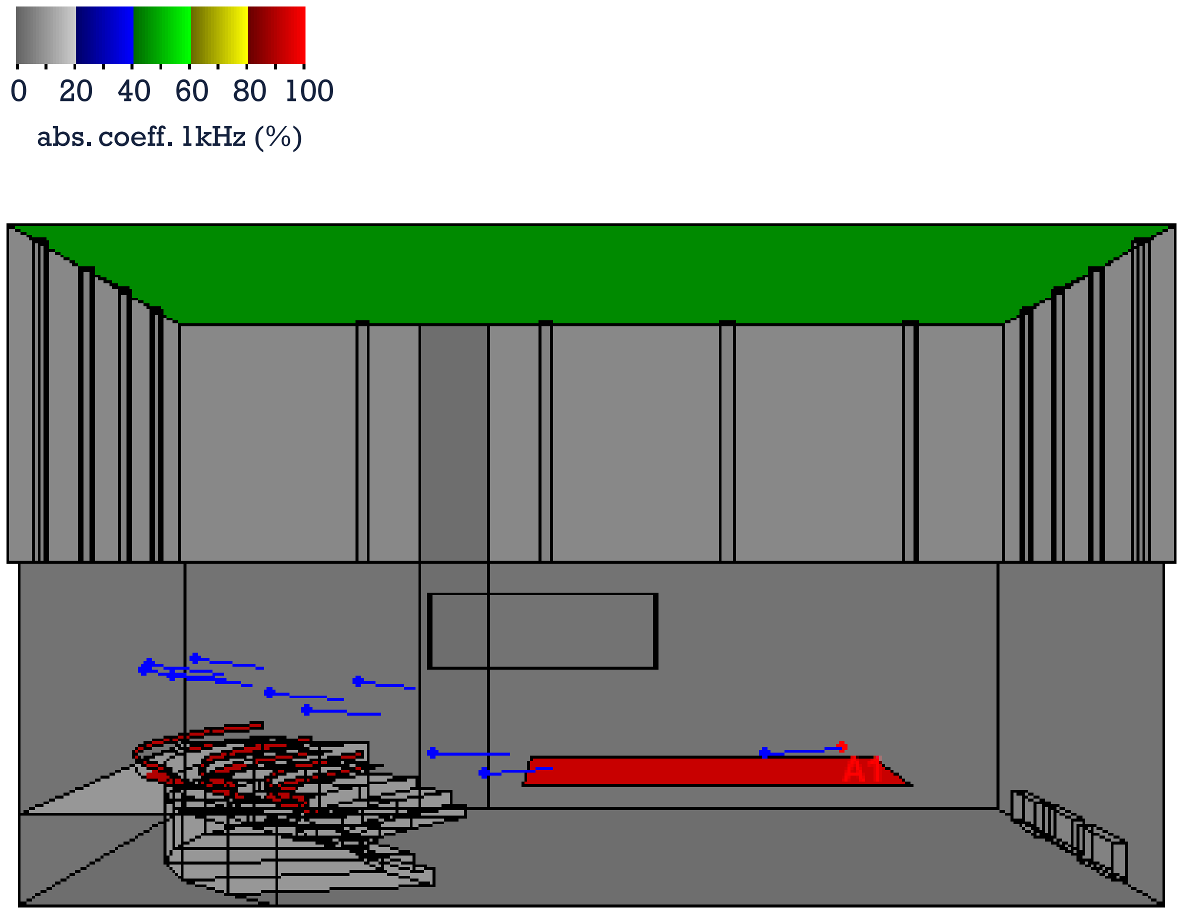
40 ms



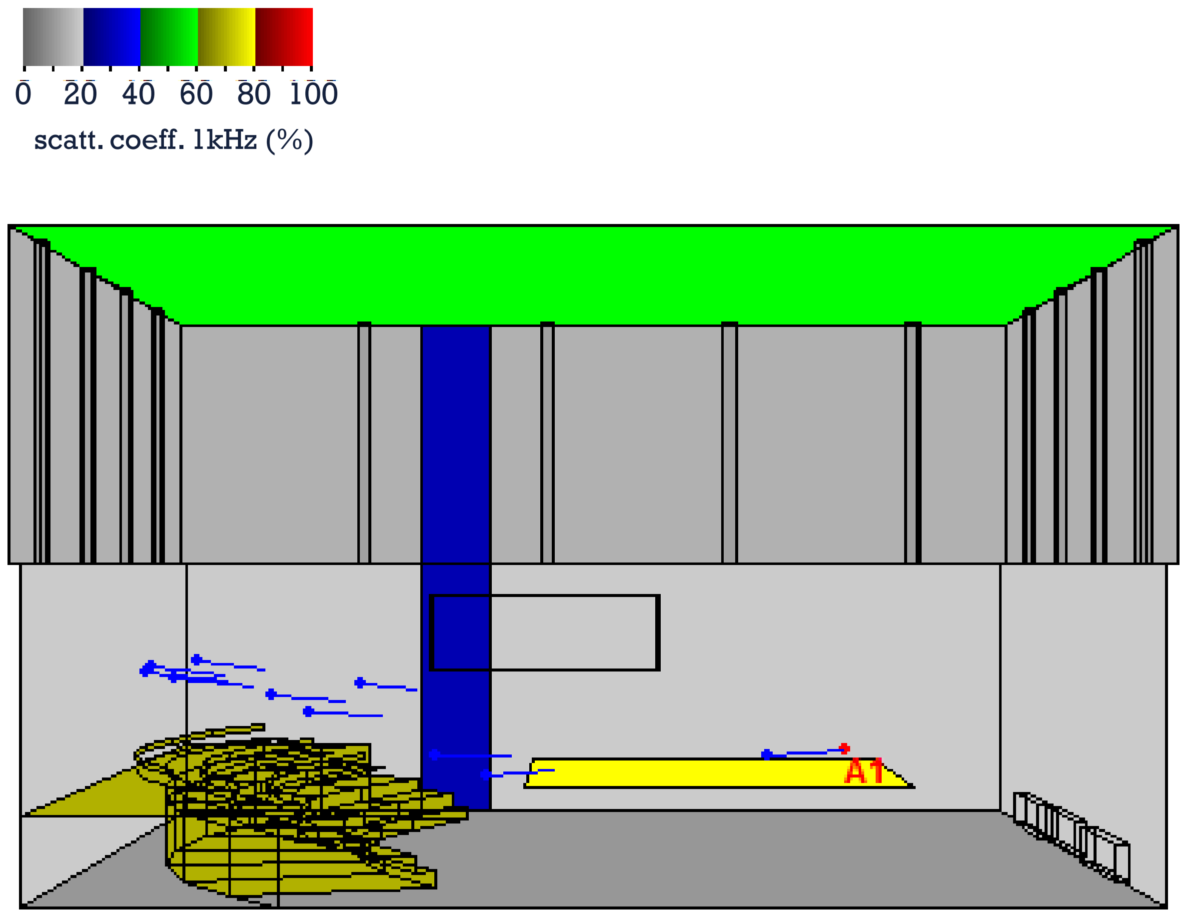
No of rays	10088
Max time	200 ms
Time step	2 ms
Min level	-5 dB

order
0
1
2
3

absorption



scattering



720°C

soda lime + calcium carbonate

2.5 wt %

5 wt %

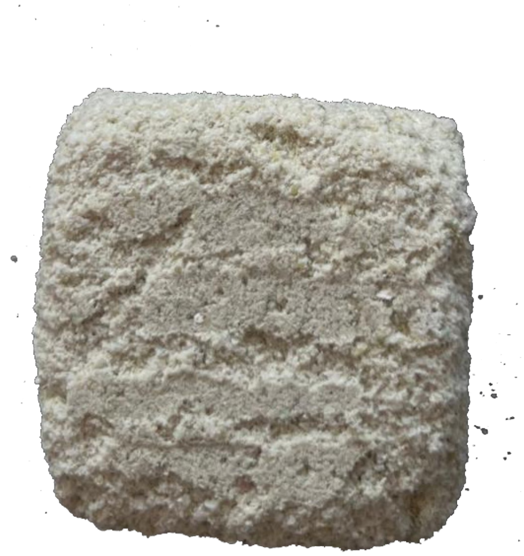
lightbulbs + eggshells

2.5 wt %

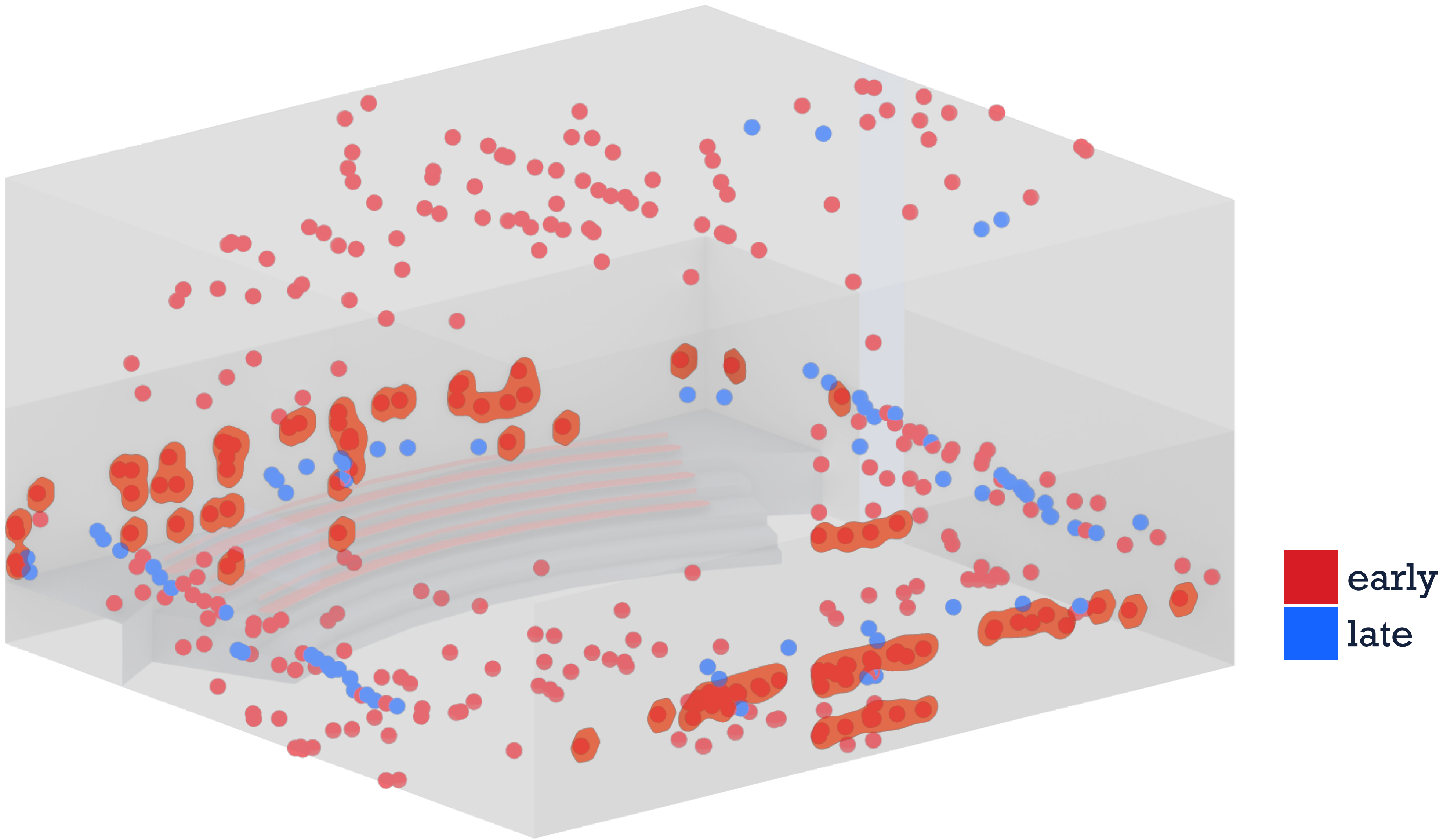
5 wt %

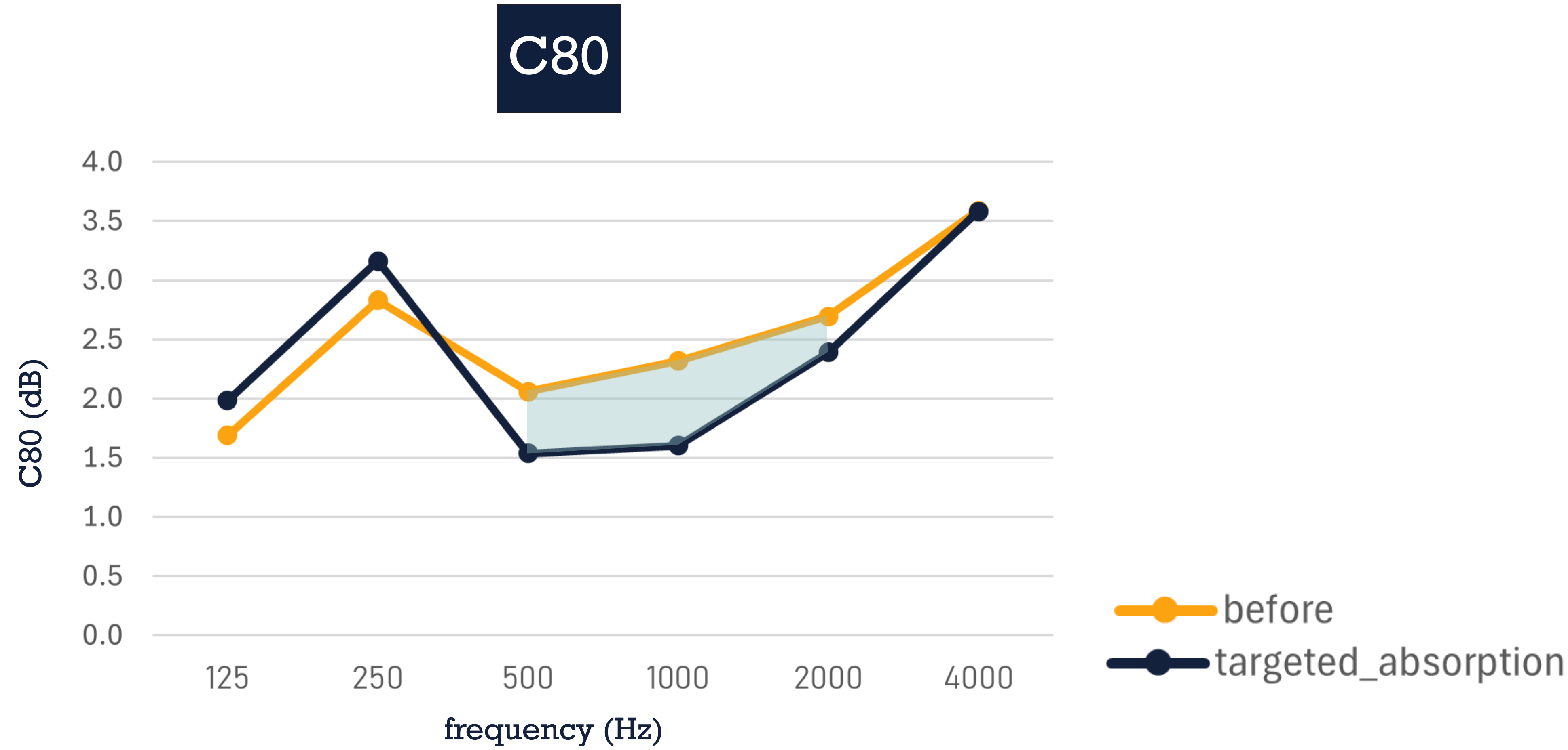
5 cm

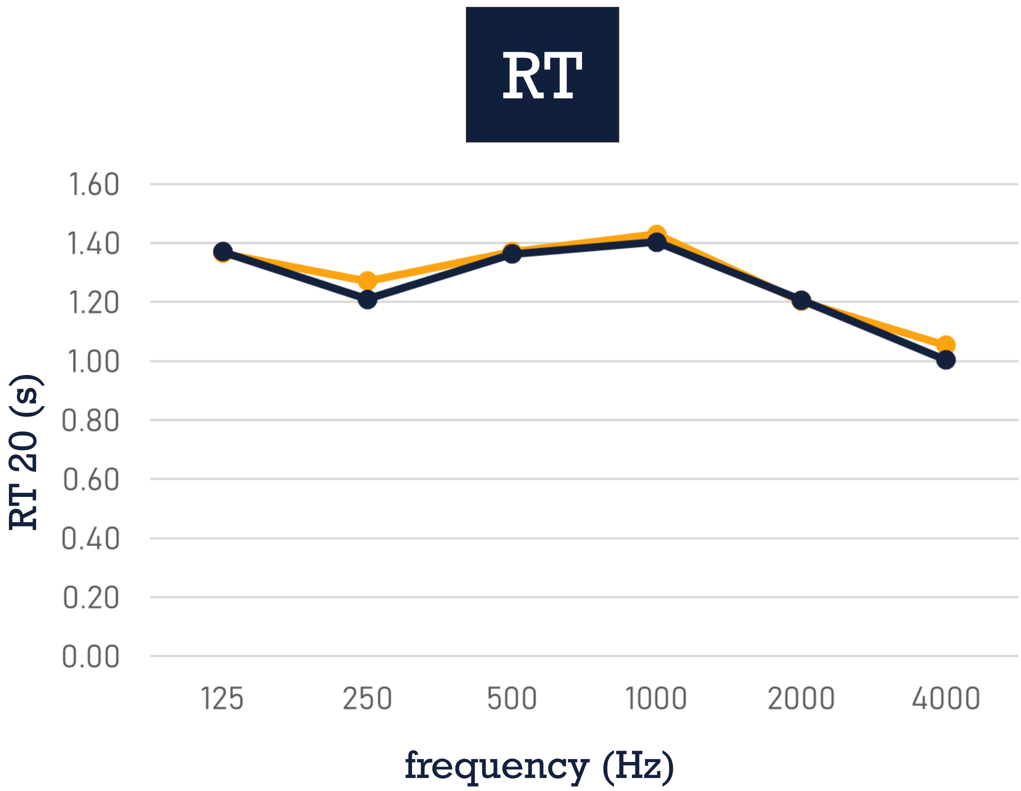
cyclon mix (CM/SL5050CC)

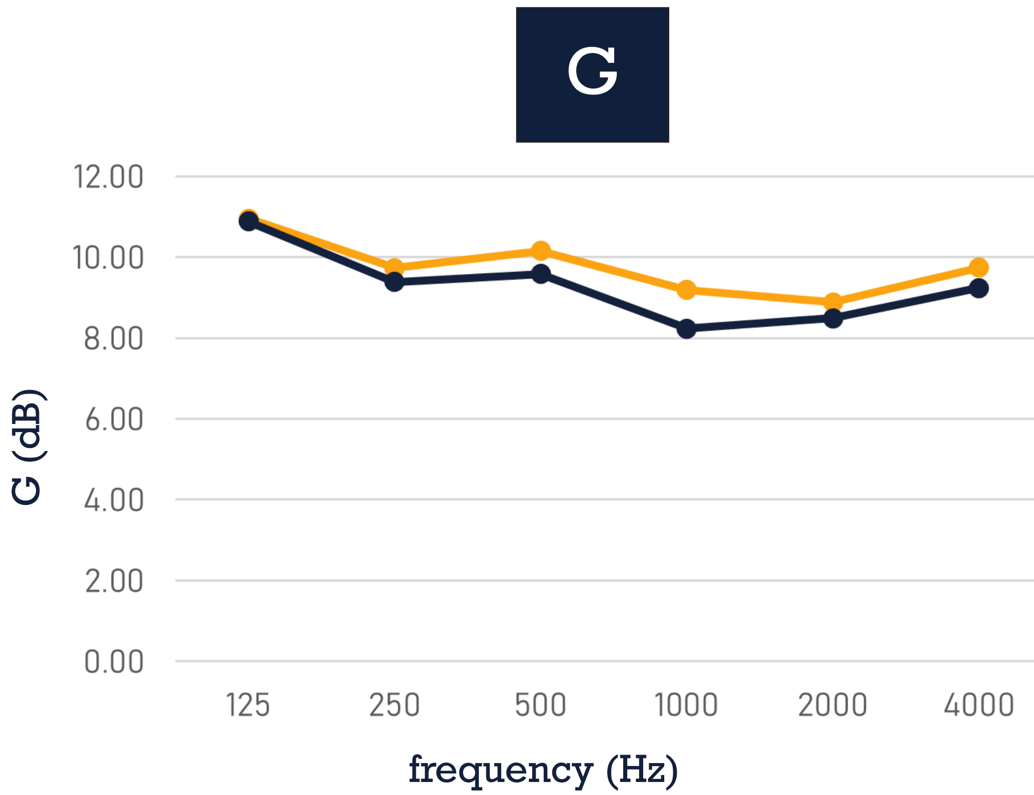


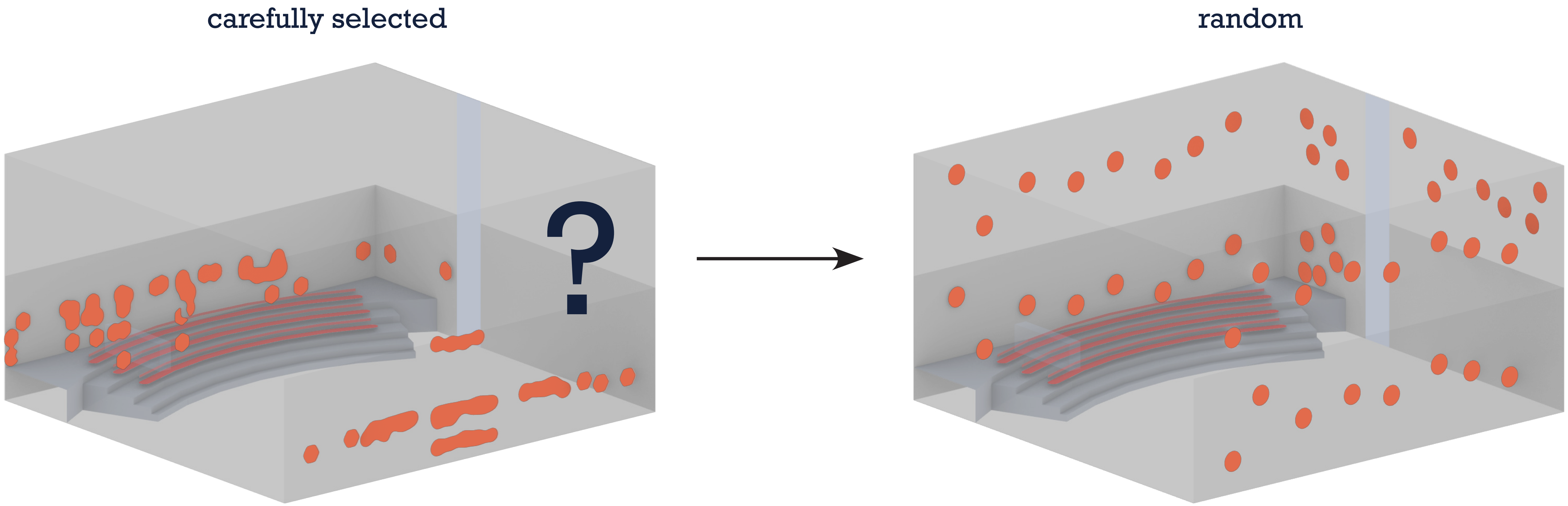
790°C → 860°C

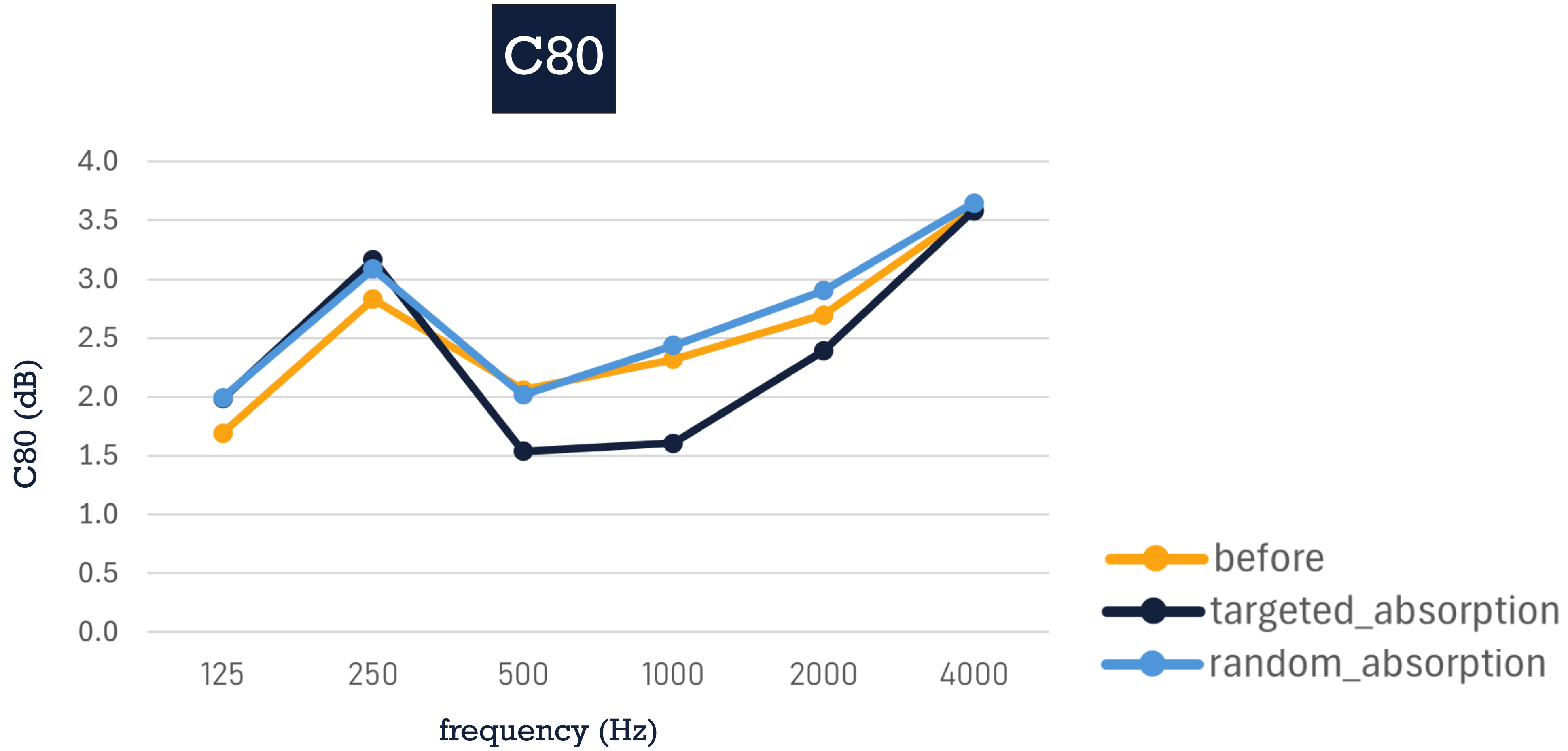

early
late

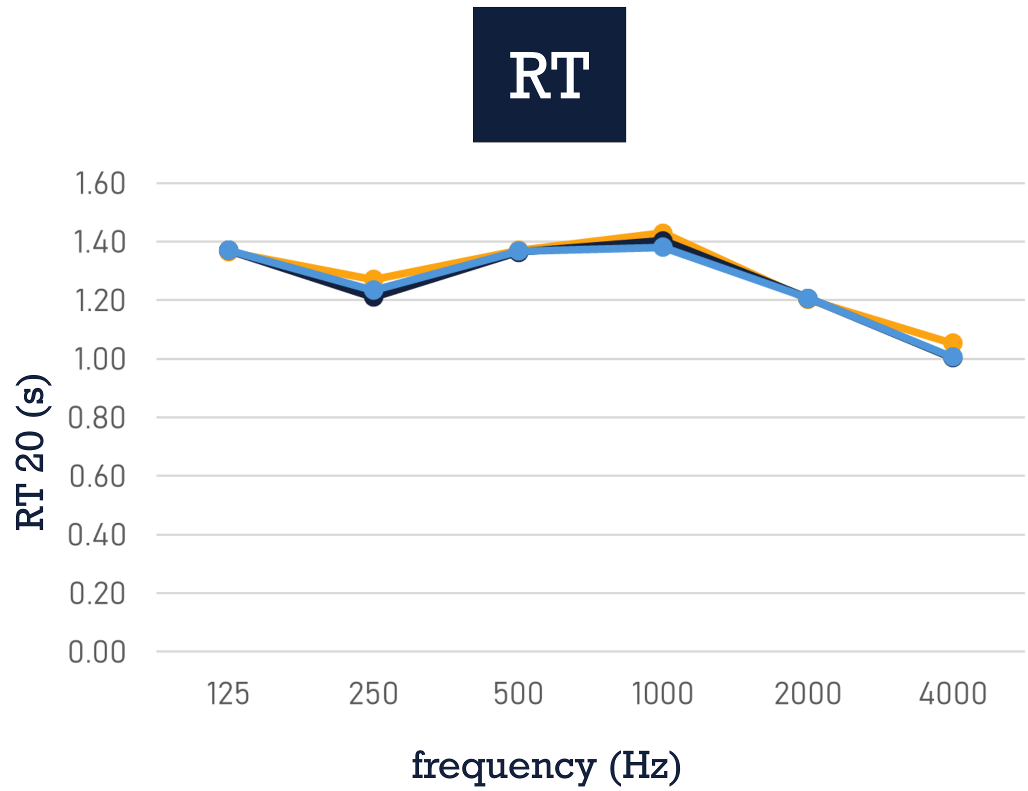

C80
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
C80 (dB)
125
250
500
1000
2000
4000
frequency (Hz)
before
targeted_absorption

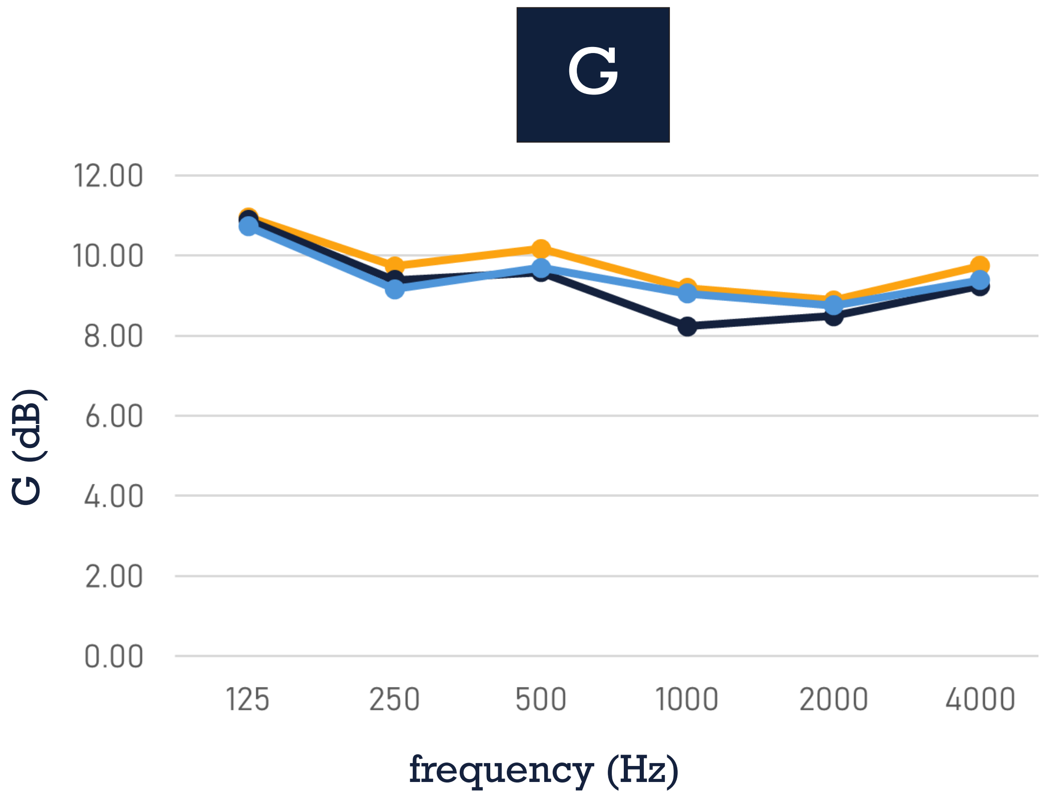

RT
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
RT 20 (s)
125
250
500
1000
2000
4000
frequency (Hz)

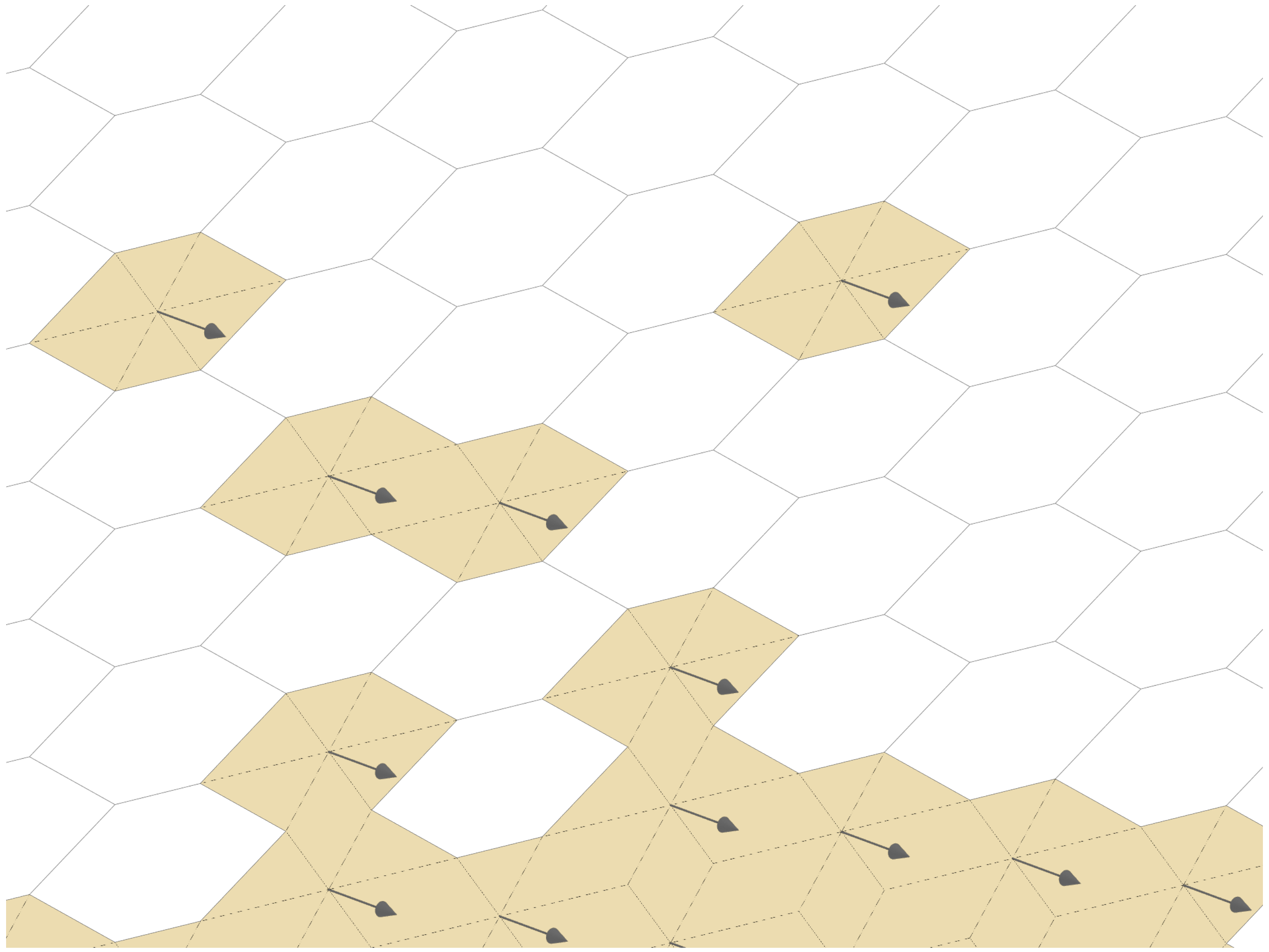

G
12.00
10.00
8.00
6.00
4.00
2.00
0.00
G (dB)
125
250
500
1000
2000
4000
frequency (Hz)

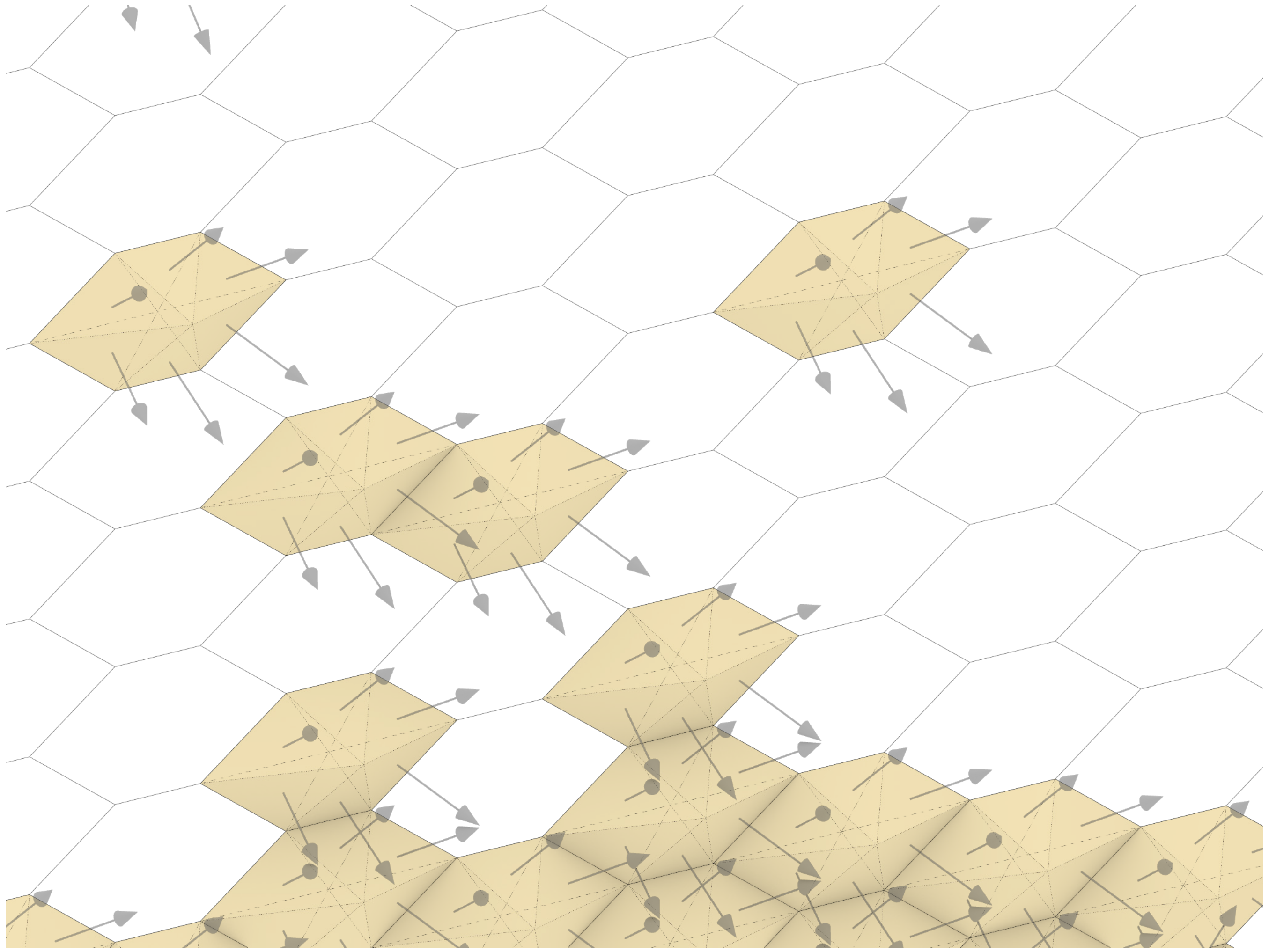

carefully selected
?
random


C80
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
C80 (dB)
125
250
500
1000
2000
4000
frequency (Hz)
before
targeted_absorption
random_absorption

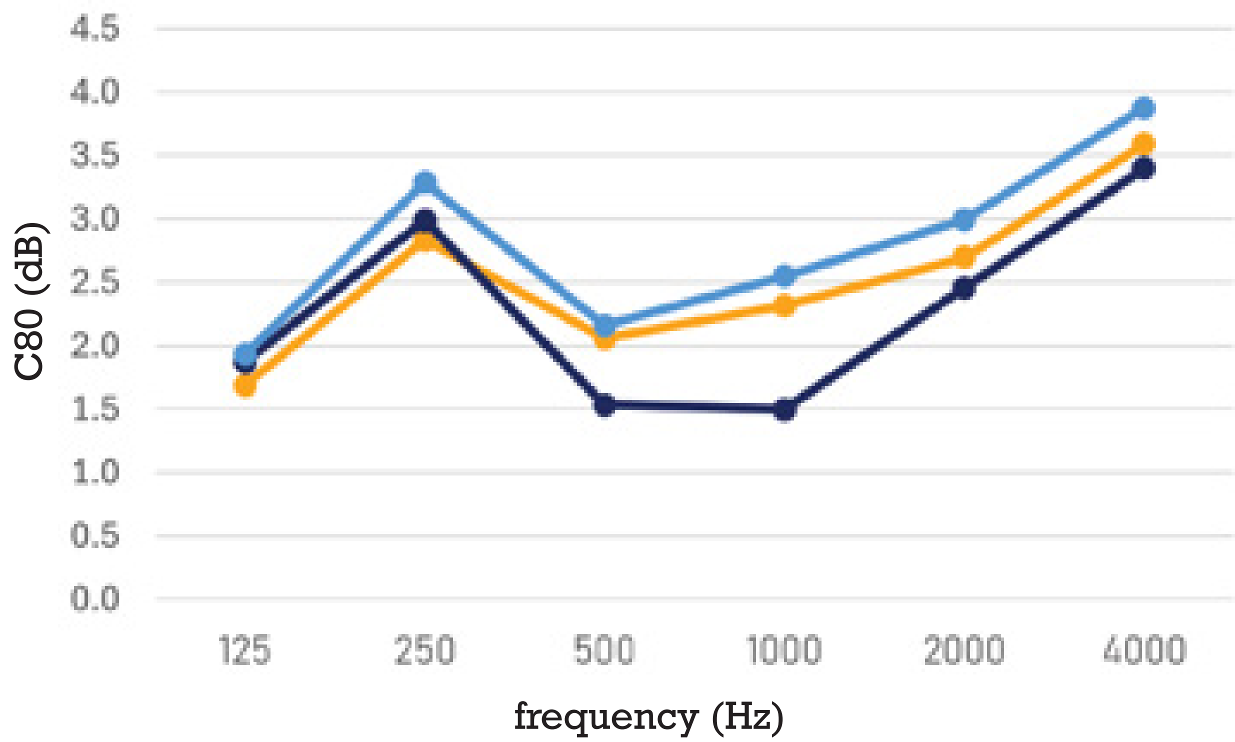

RT
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
RT 20 (s)
125
250
500
1000
2000
4000
frequency (Hz)


G
12.00
10.00
8.00
6.00
4.00
2.00
0.00
G (dB)
125
250
500
1000
2000
4000
frequency (Hz)





C80


4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
C80 (dB)
125
250
500
1000
2000
4000
frequency (Hz)

foaming agent concentration

light bulbs + eggshells

860°C

2.5 wt %

5 wt %

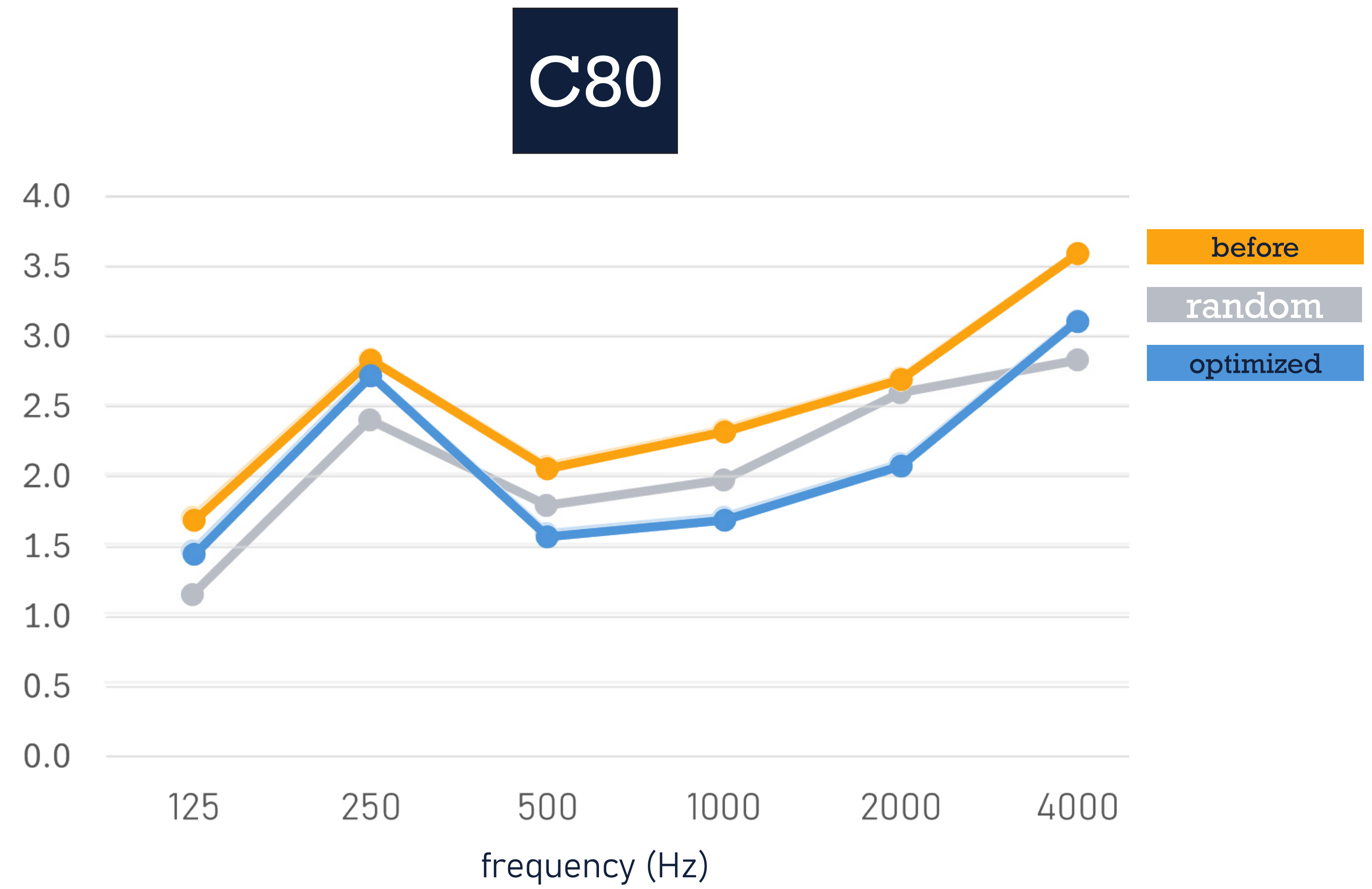
foaming agent concentration

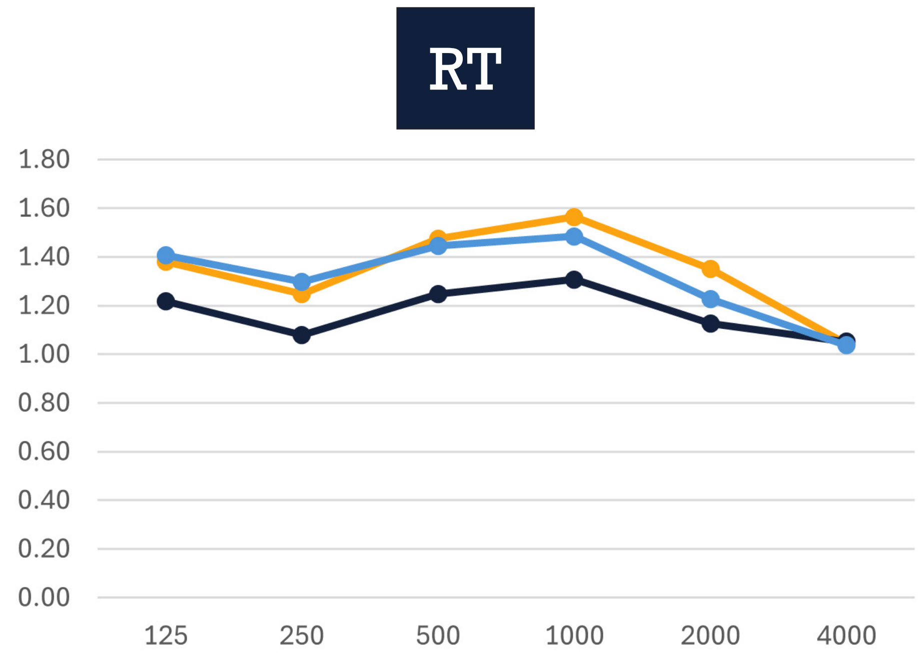
5 cm

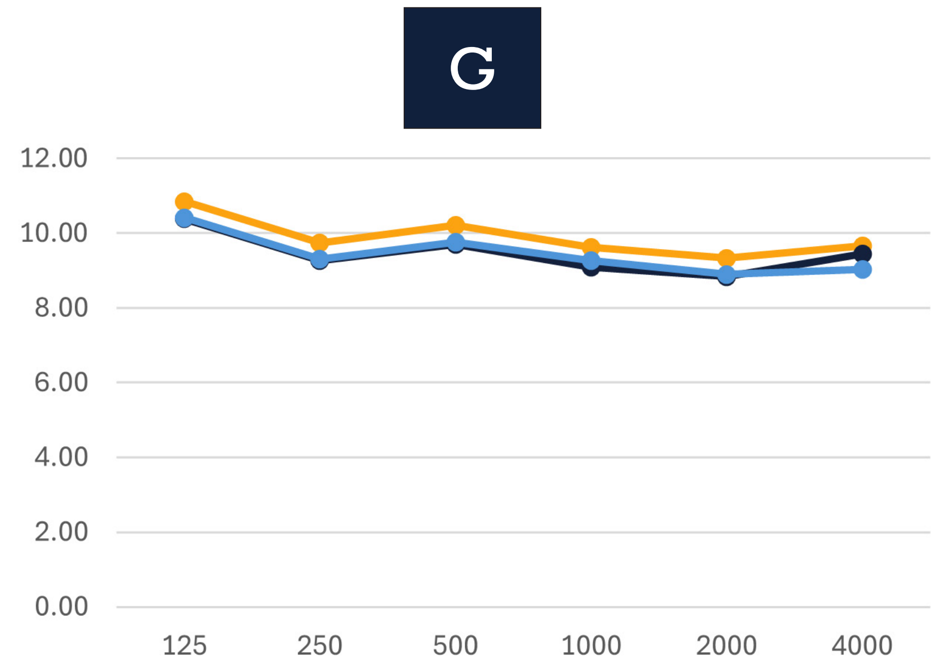
foaming agent concentration

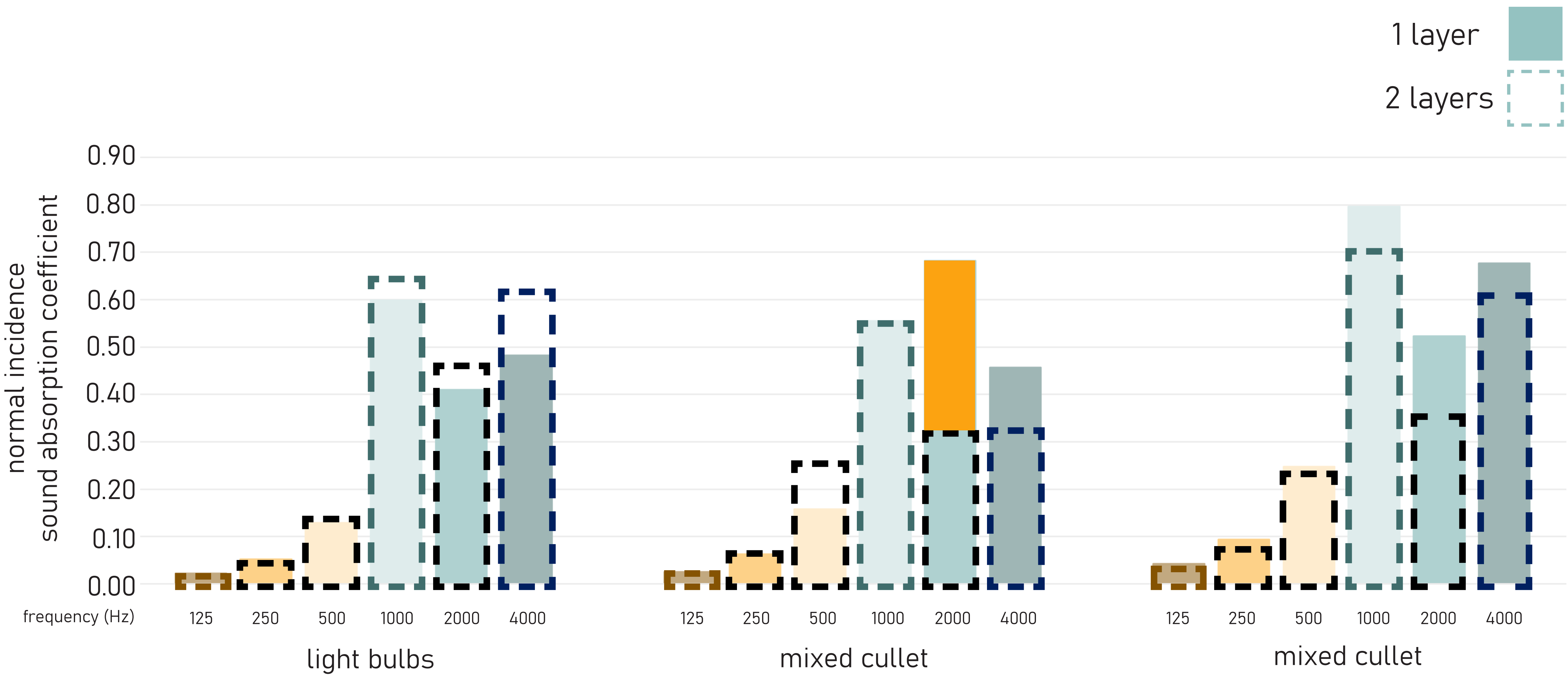
light bulbs + eggshells

860°C


C80
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
125
250
500
1000
2000
4000
frequency (Hz)
before
random
optimized


RT
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
125
250
500
1000
2000
4000


G
12.00
10.00
8.00
6.00
4.00
2.00
0.00
125
250
500
1000
2000
4000


1 layer
2 layers
normal incidence
sound absorption coefficient
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
frequency (Hz)
125
250
500
1000
2000
4000
light bulbs
mixed cullet
mixed cullet