Next-Generation Acoustic Simulation

Streamlining Low-Frequency Design with Integrated Ray Tracing and FEM Analysis

Donato Masci

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STUDIO SOUND SERVICE

Donato Masci

Who we are

Who we are

Studio Sound Service is a well-established design and consultancy company that specialises in every aspect of acoustics and sound systems.

Founded in 1983
SSS has built an enviable reputation for the production of world class performance and recording spaces, from personal studios to large scale film, broadcast and corporate facilities.

By combining aesthetic and technical skills with decades for experience SSS strives to make every project successful, both sonically and visually.

ADR, Post & Broadcast. Cinema Mixing studios. Gaming Studios

- Iyuno (ex SDI Media) Acoustic Designers (more than 15 countries)
- Cinecittà Studios (Postproduction Facility 2020 Renewal) @ Rome
- Dubbing Brothers (Italy, USA)
- 3Cycle postproduction Facility @ Rome
- FOX Dolby Atmos Studios @ Rome (IT), Münich (DE), London (UK)
- Netflix Facility @ Rome
- Disney Facility @ Warsaw (PO), Milan
- inHouse (Oscar winner Sorrentino) @ Roma

Music Studios (400+)

- Cicaleto Recording – Francesco Ponticelli @ Arezzo
- Aemme Recording Studio – Salvatore Addeo @ Lecco
- D:POT Recording Arts @ Prato – Fabrizio Simoncioni
- Mulinetti Studio @ Genova – Alberto Parodi
  Resolution Award 2015 Best Audio Facility
- The Garage @ Civitella v.d.C. (AR)
  Resolution Award 2014 Best Audio Facility
- House of Glass @ Viareggio (LU) – Gianni Bini
  Resolution Award 2013 Best Audio Facility
- SonicFab Studio @ Pioltello (MI)
- Waves Music @ Genova
- Marco Borsatti Studio @ Bologna
- Pop Fiction – Janie Price @ Firenze
- Sugarmusic @ Milano
- Experimental Studios @ Torino

Dolby Atmos Music Studios: 50+ rooms
Dolby Atmos Home Entertainment Studios: 80+ rooms
Dolby Atmos Theatrical Studios: 10+ Theatres

Personal Studios

- Andrea Bocelli, Asaf Avidan, Biagio Antonacci, Daniele Silvestri, Damian Lazarus, Diego Calvetti, Enrico Cremonesi (Fiorello), Enrico Melozzi, Fabio Rovazzi, Federica Vincenti (Michele Placido), Gabry Ponte, Giorgia Angiuli, Irko (Kanye West sound engineer), Luca Agnelli, Marco Masini, Marco Messina (99 Posse), Merk & Kremont, Nari&Milani, Paolo Sandrini, Petra Magoni, Piero Pelù, Pino Iodice, Renato Zero, Vinai.

- Barys Arena (ice hockey) @ Astana, Kazakhstan
- Chorus Life (arena e cittadella) @ Bergamo
- Stadio Tardini @ Parma

- Hospitals: Nuovo Ruggi @ Salerno, Cesena

- George Lucas Home Theater, Italy
- Cinema Barberini @ Roma

- Chiesa Santa Maria Nuova (Arch. M. Botta) @ Terranuova B. (AR)
- Duomo di Siena new audio system

- Prada Auditorium and Conference Room via Orobia @ Milano
- Presentation room Ferrari HQ @ Maranello (MO)
- Siemens HQ @ Milano
- Heineken HQ @ Milano
- Leonardo Elicotteri @ Milano

- Four Seasons Hotel @ Firenze
- Portrait Milano – Ferragamo @ Milano
- Caffè dell'Oro – Ferragamo @ Firenze
- Hotel Veronesi (Calzedonia) @ Verona

- EVAC Dubai Metro
- EVAC Bahrain and Islamabad airport (THALES)
- EVAC Scuola di Magistratura Castelpulci @ Scandicci Firenze

- Teatro del Popolo @ Castelfiorentino (FI)
- Teatro del Popolo @ Colle di Val d'Elsa
- Teatro del Popolo @ Poggibonsi
- Teatro il Ferruccio @ Empoli
- Teatro Marconi @ Pistoia
- Teatro Nazionale @ Firenze

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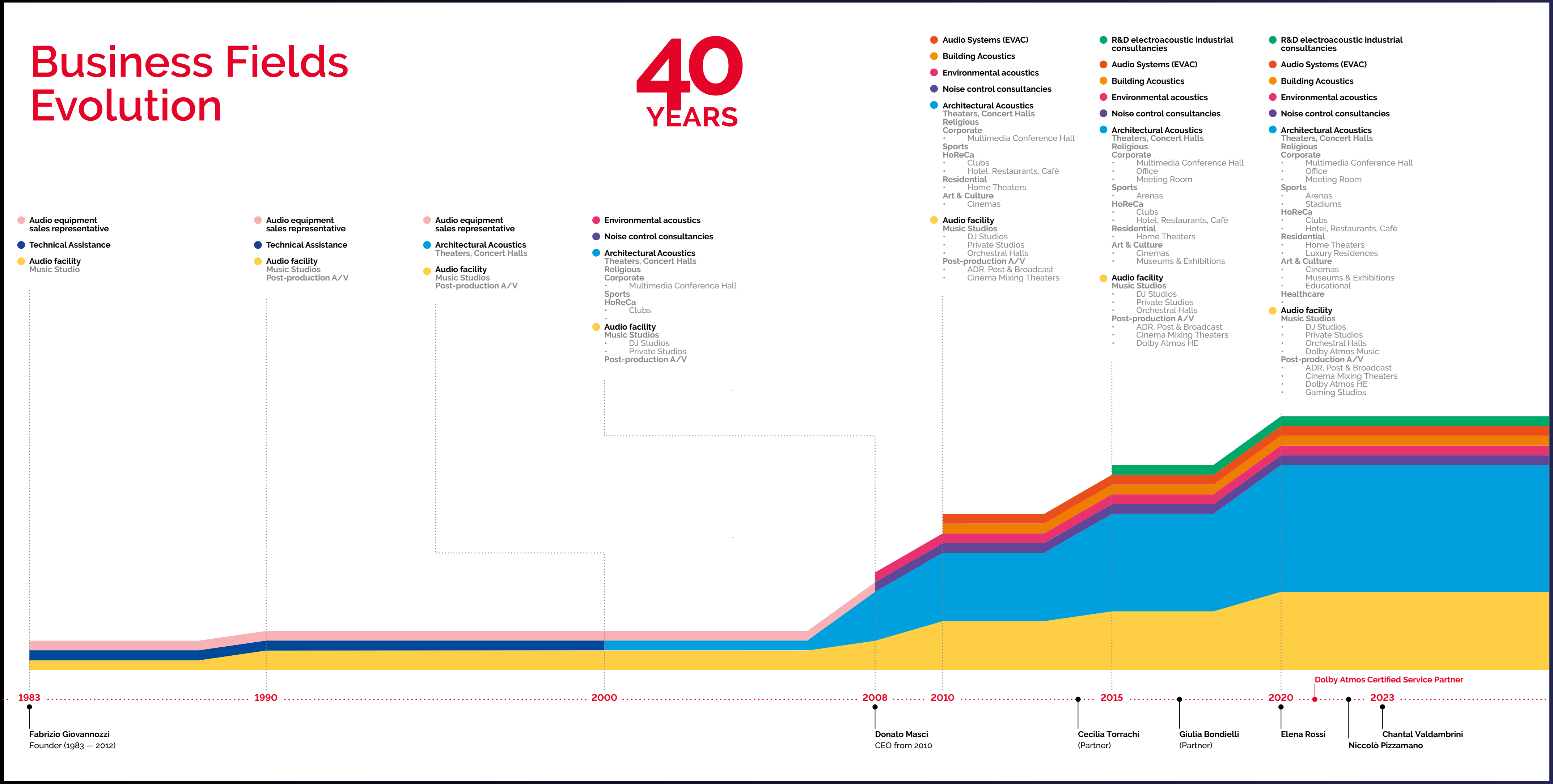
Studio Sound Service – Business Fields Evolution



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Countries where we operate

Paesi in cui siamo attivi
Countries where we operate

Bahrain	Mexico
Canada	Netherlands
China	Oman
Czech Republic	Pakistan
Denmark	Poland
Dubai	Russia
Finland	Saudi Arabia
France	Spain
Germany	Switzerland
Hong Kong	Thailand
Hungary	Turkey
Italy	UK
Kazakhstan	USA

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Dolby CSP

Studio Sound Service is the only Italian Dolby CSP.

We can provide design, commissioning and consultancy services worldwide with Dolby's certified quality standards.

Dolby
Certified service partner

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CEDIA associated

CEDIA

MEMBER 2024 - 2024

Studio Sound Service Srl

Industry-Related Professional

CEDIA Members are smart home professionals providing comfort, control, connection, and entertainment for clients to experience the best moment in life in their homes.

The Association for Smart home Professionals™

CEDIA Member Code of Conduct

Each member of CEDIA shall agree to adhere to the following:

1. Provide to all persons truthful and accurate information with respect to the professional performance of duties.

2. Maintain the highest standards of personal
conduct to bring credit to the custom electronic and design industry.

3. Promote and encourage the highest level of ethics within the profession.

4. Responsibly uphold all laws and regulations relating to CEDIA policies and activities.

5.Strive for excellence in all aspects of the industry.

6. Use only legal and ethical means in all ndustry activities.

7.Protect the public against fraud and unfair practices.

8.Use written contracts clearly stating all charges, services, products and other essential information.

9. Demonstrate respect for every professional within the industry by consistently performing at or above the standards acceptable to the industry.

10. Make a commitment to increase professional growth and knowledge by participating in technical and industry business training.

11. Contribute knowledge to professional meetings and journals to raise the professionalism of the industry.

12. Maintain the highest standards of safety

13. When providing services or products, maintain in full force adequate or appropriate insurance.

14. Cooperate with professional colleagues, suppliers and employees to provide the highest quality service.

15. Extend these same professional commitments to all persons supervised
or employed.

16. Subscribe to CEDIA's Code of Ethics and abide by the CEDIA Bylaws.

Professional background

Professional vs Consumer Audio: Core Differences

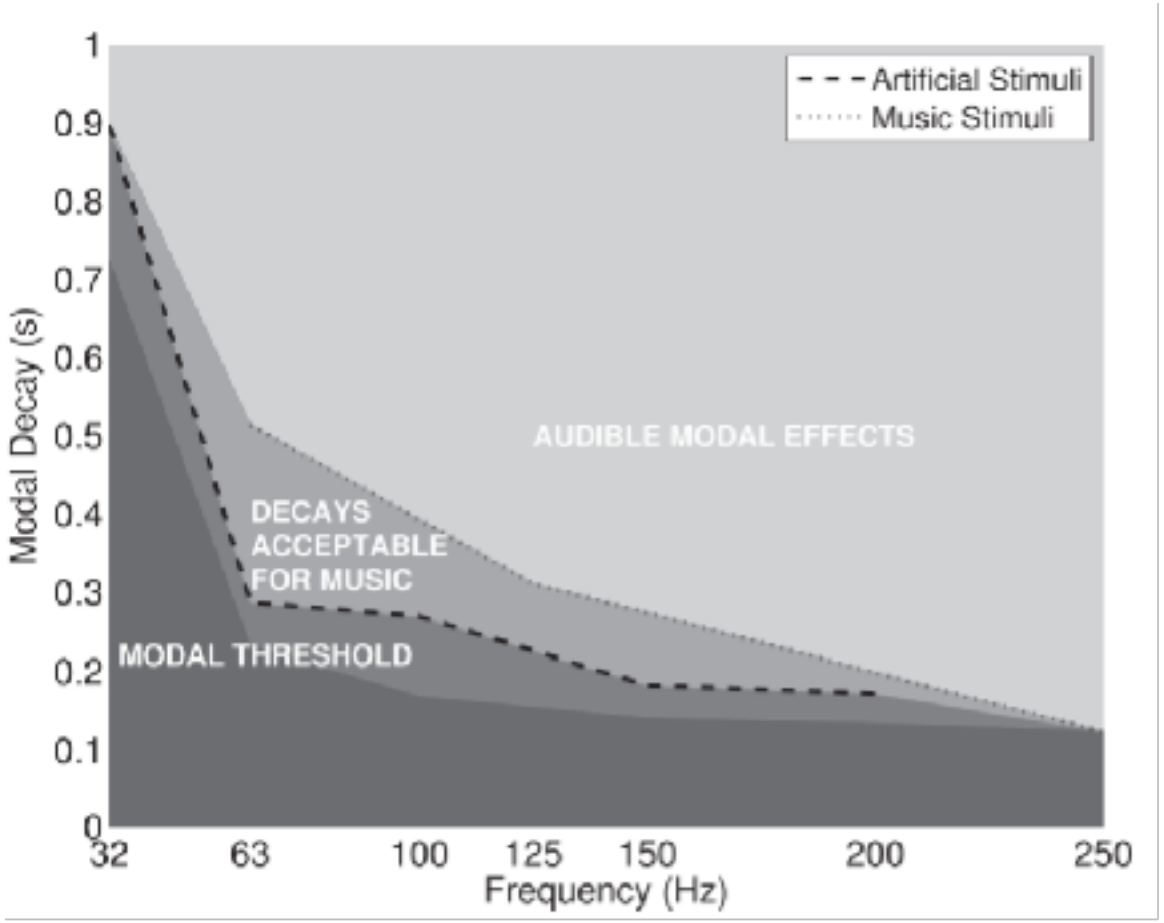
1. Professional Audio:

- Single-user optimization and precision at listening position
- Acoustic solutions over electronic correction

2. Consumer audio:

- More emphasis on room-wide uniformity
- Electroacoustic correction and active absorption are highly valued (try to reduce traditional acoustic treatment)

Perception limits of LF reverberation



Perception limits of low-frequency reverberation (by Bruno Fazenda)

- **The Chart shows the limits of perception of modal decay for various sound sources under controlled laboratory conditions. The absolute limits are in effect the point where further reduction in decay time by acoustic or other means would be futile.**
- **The critical frequency would seem to be 63Hz and resonant decay above that is noticeable if longer than 0.2s. Above 250Hz modes become reverberation which is more likely to be significant in terms of spatial awareness. Below 63Hz modal decay can increase exponentially to almost 1s at the limit of our hearing.**
- **It is logical that reverberation control should match as closely as possible the threshold for modes as basically they are the same thing but with different distribution.**

Optimal Reverberation times

They depends on the intended use:

Recording: Dubbing studios (ADR)

1. have a neutral tonal coloration
2. not to exceed the low frequency modal perception threshold

- LF reverberation time 0.30÷0.35s
- HF flat reverberation time 0.10÷0.15s

Dolby Atmos Home Entertainment

(Where broadcast and TV contents are mixed and post produced)

- LF reverberation time 0.35÷0.45s
- HF flat reverberation time 0.15÷0.30s

Dolby Atmos Cinema Mixing Room

(Where movies are mixed)

- LF reverberation time 0.40÷0.80s
- HF flat reverberation time 0.20÷0.40s

Cinecittà Sala A

Roma

Cinecittà Sala A

Roma

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Cinecittà Sala A

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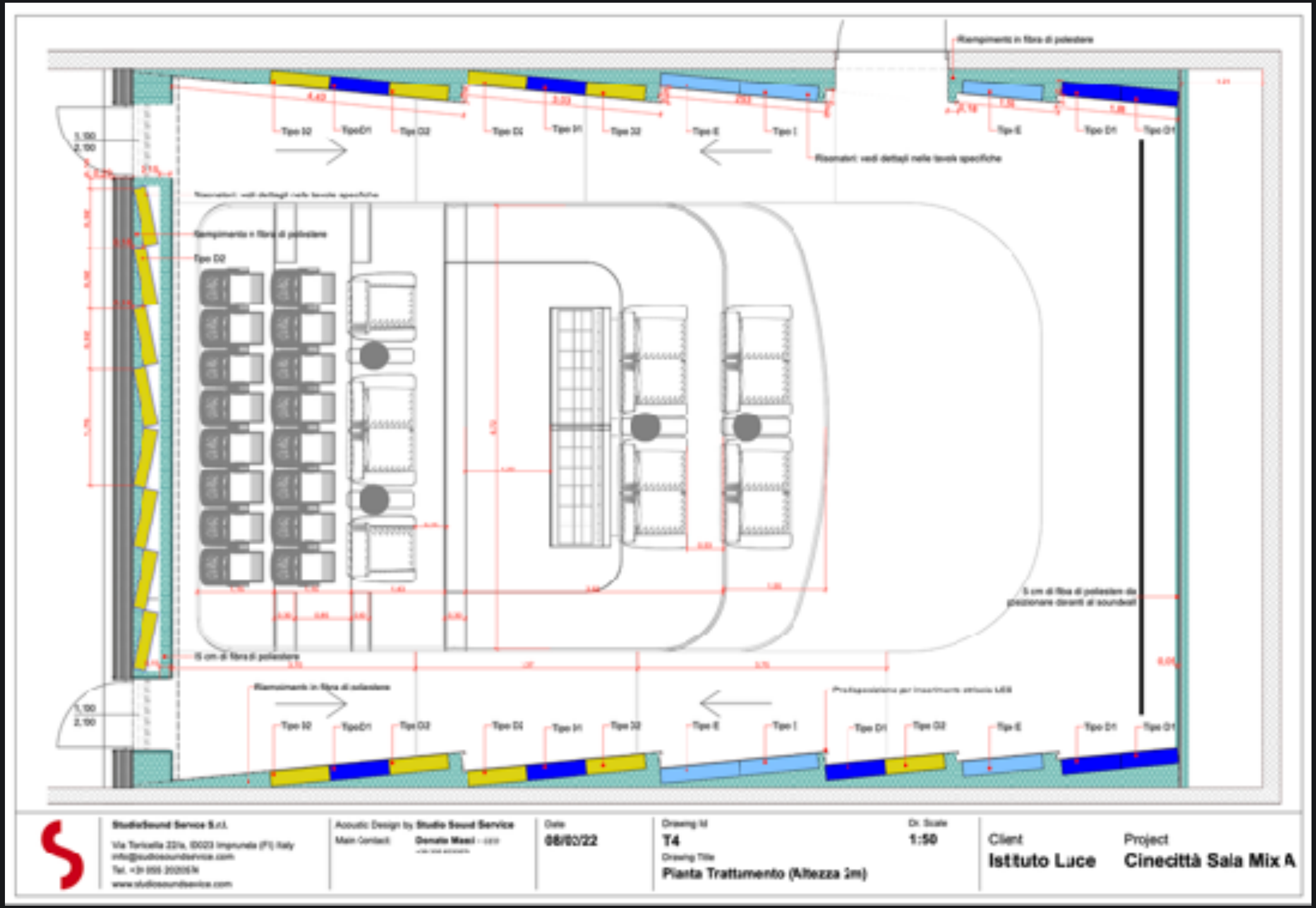
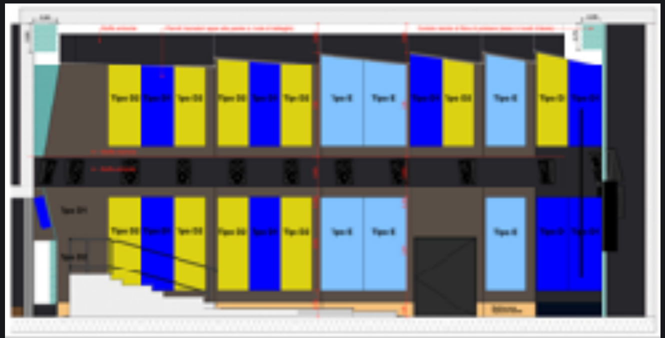
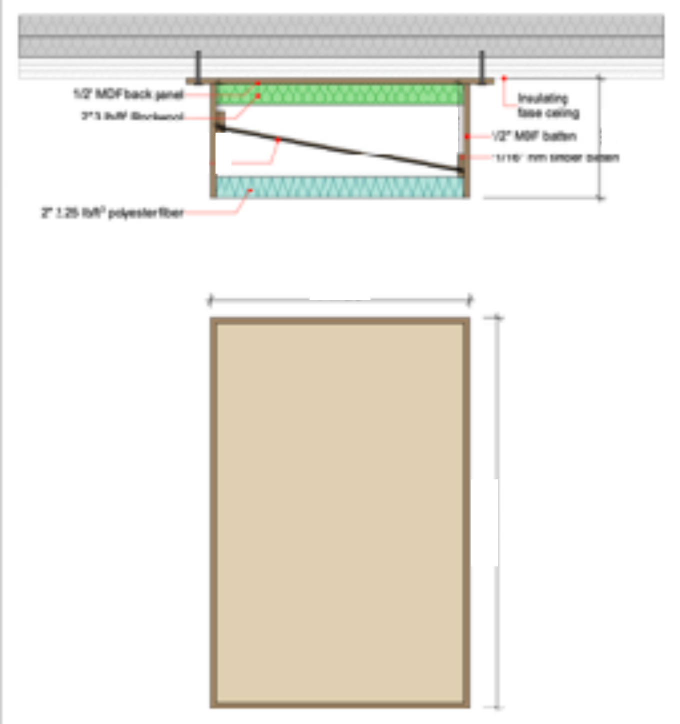
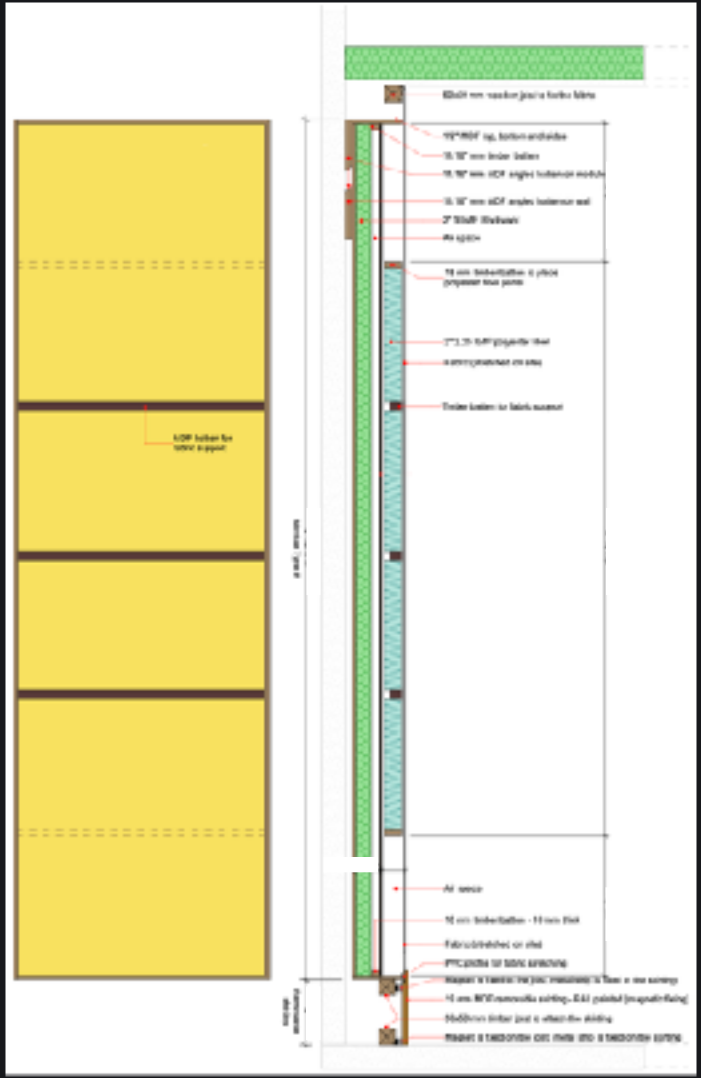
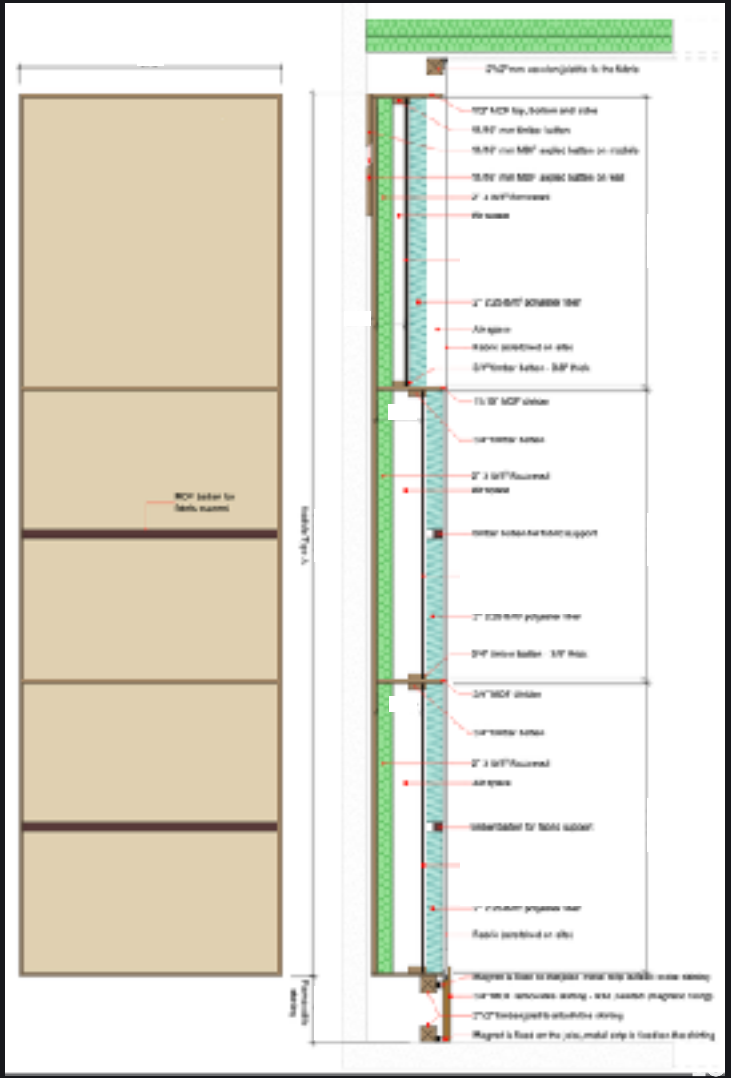




Low Frequency Absorption







Cinecittà Sala Color Blu

Roma

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Cinecittà Sala Color Blu

Roma

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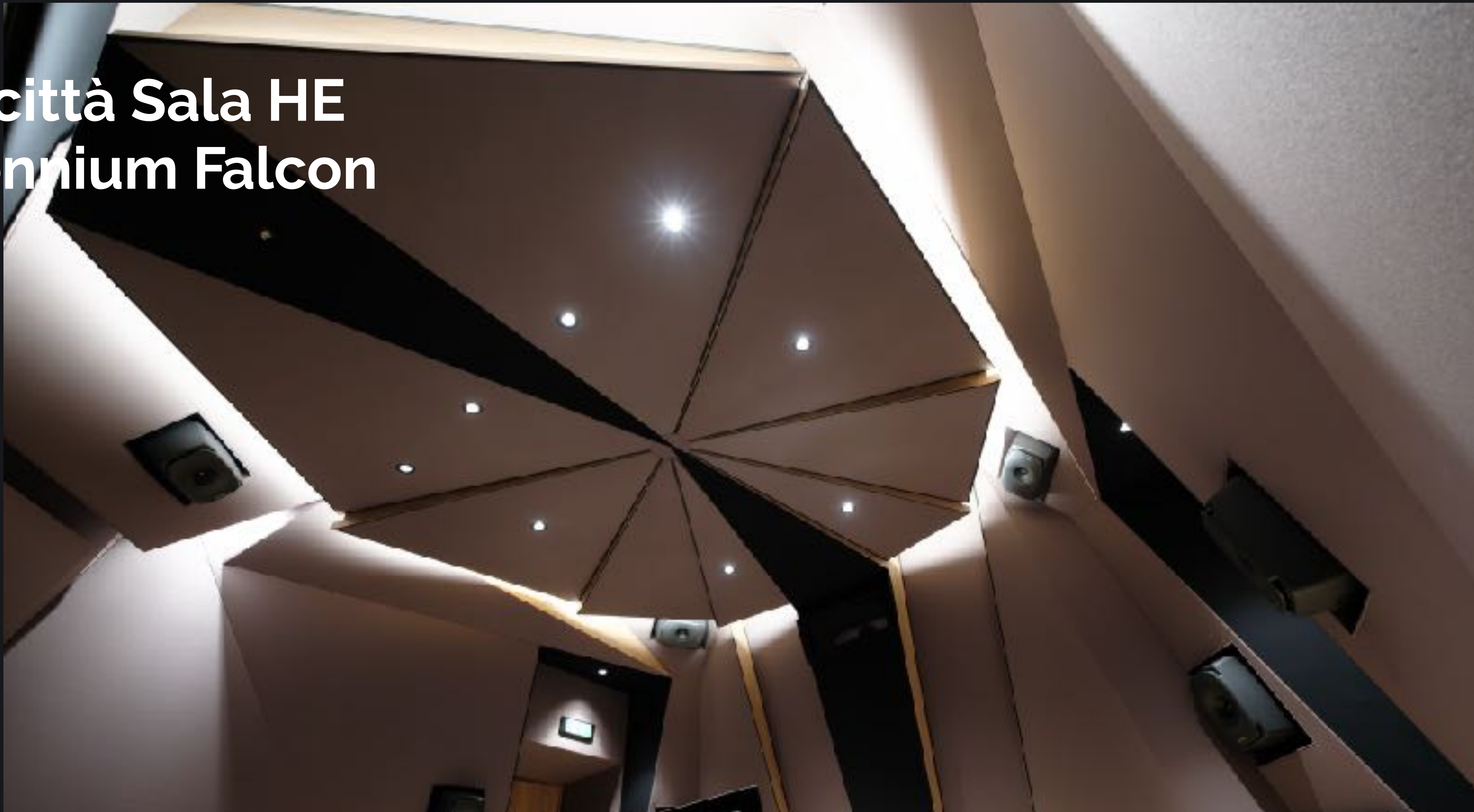
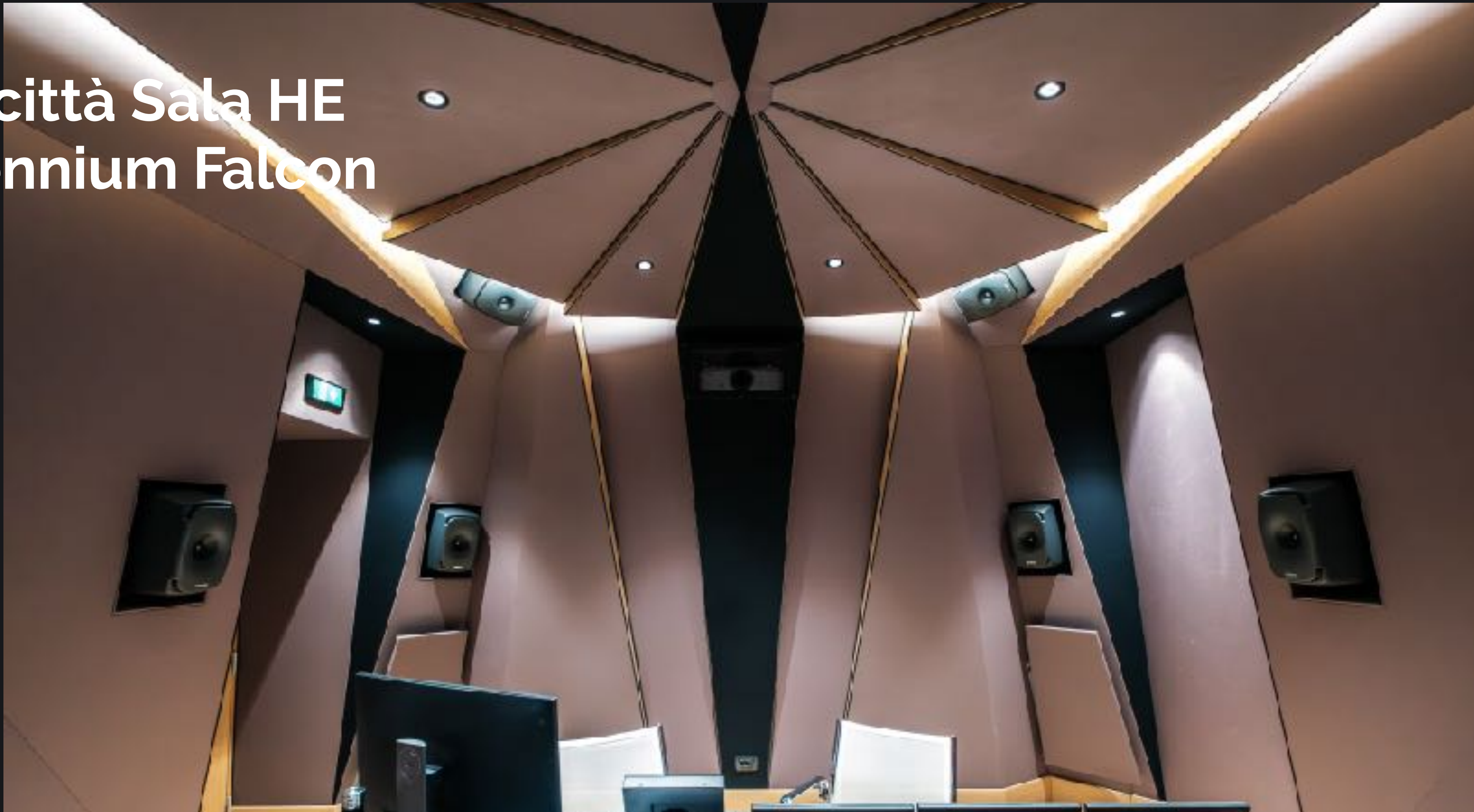
Cinecittà Sala HE Millennium Falcon

Roma



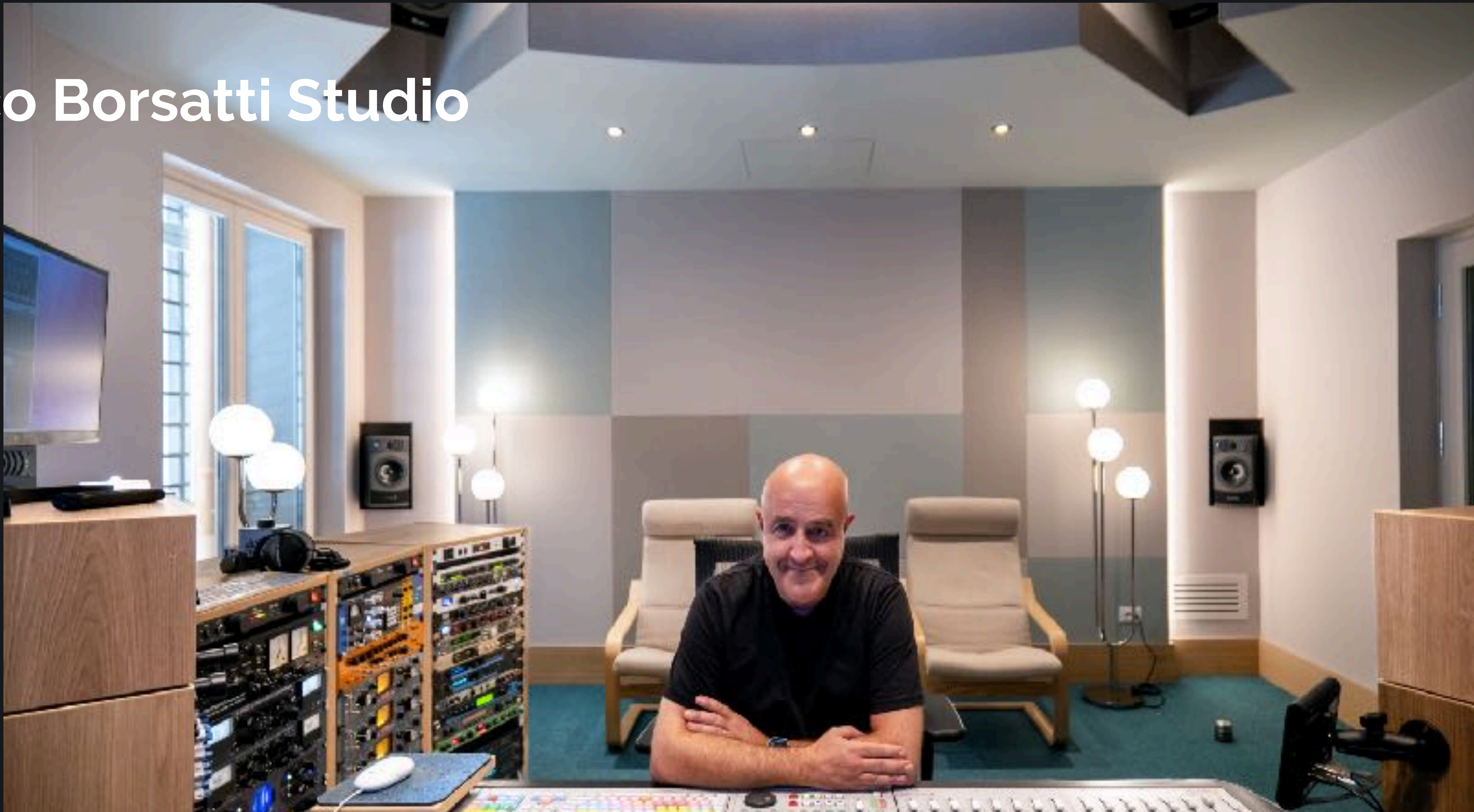
Cinecittà Sala HE Millennium Falcon

Roma



Marco Borsatti Studio

Bologna



Marco Borsatti Studio

Bologna

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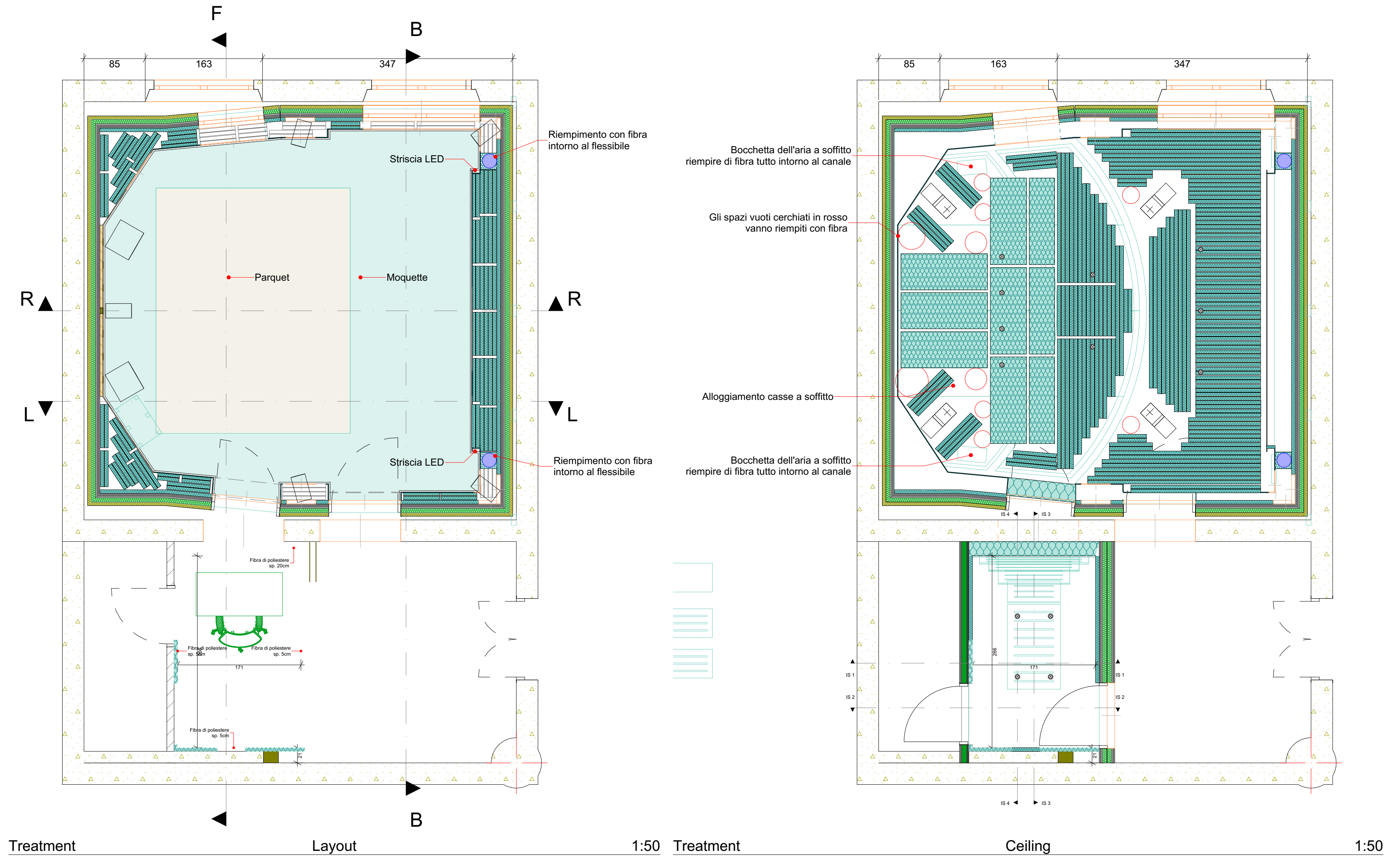
Acoustic Treatment with suspended panels



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Tel. +39 055 2020574
www.studiosoundservice.com

Acoustic Design: **Studio Sound Service**

Date	Drawing Number	Title	Dr. Scale	Client	Project
08/06/2023	**9 /4**	**Treatment** Layout	**1:50**	**Marco Borsatti**	**Studio Borsatti**
Revision **Definitive**					

SoundBeat 3 - IRKO (Kanie West)

Pasadena, USA

Fabio Piazzalunga

Florence

SonicFab

Pioltello

Sudestudio

Guagnano – LE

Cicaleto Recording

Arezzo

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Room Design: Treatment Strategy

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...Perfect Absorber?

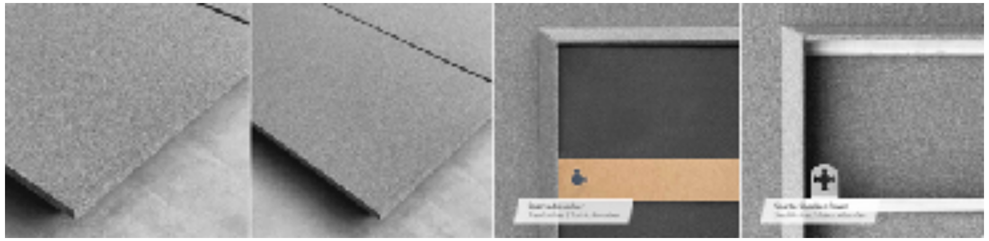
The perfect absorber doesn't exist, but fortunately it's not necessary to achieve perfect silence…

it would be sufficient to reach a value close to the perception threshold!

This is true for professionals, so why it couldn't be true for the consumer world?

Porous Absorber (velocity)

Wools, extruded materials etc.

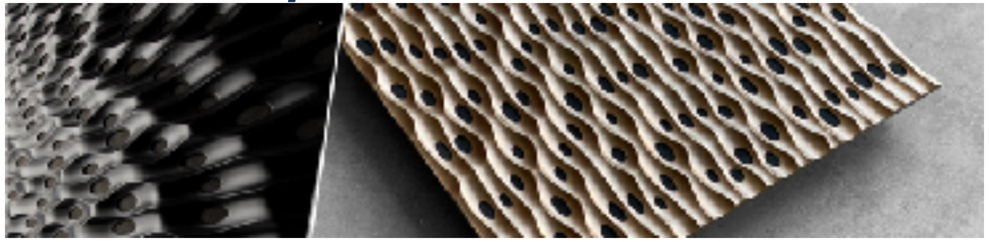


Membrane Resonator (pressure)

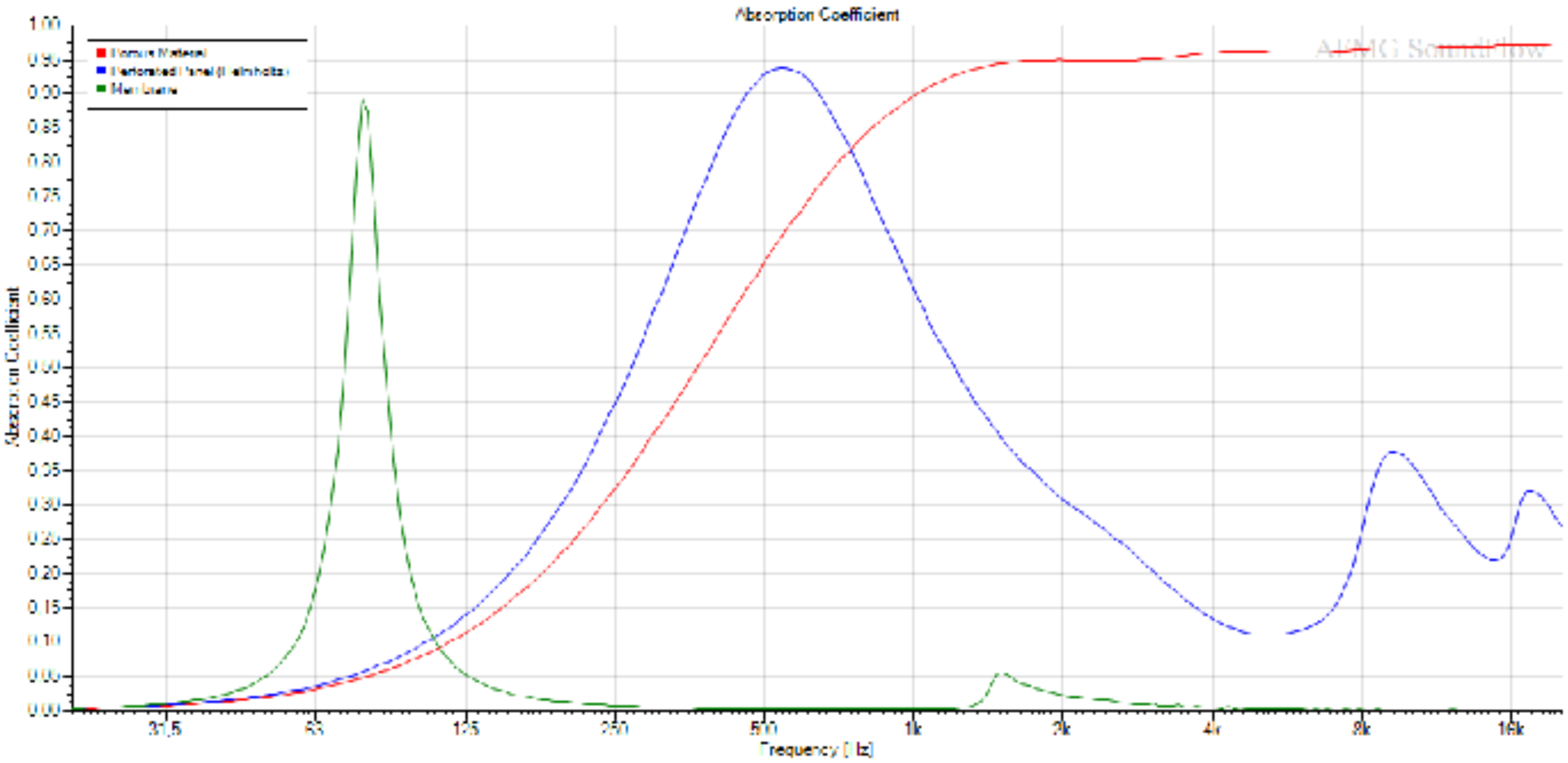
Panel absorber

Helmholtz Resonator (pressure)

Perforated panel



Acoustic Treatment Strategies



- **Below 100-120 Hz: Membrane absorbers**
- **100÷250 Hz: Helmholtz resonators**
- **Above 250 Hz: Porous materials**

Room Acoustics: Key Challenges and Solutions

1. Dual Nature of Problems:

- Room modes
- Loudspeaker boundary interactions
  —> Complex interweaving of both issues

2. Simulation Limitations:

- Difficulties in accurately modeling combined effects
  —> Need for practical, proven solutions

3. Absorption Strategy:

- Use of proven, specific absorption designs
  —> Preference for broadband vs single-frequency solutions
  (contradiction with common HiFi industry claims)

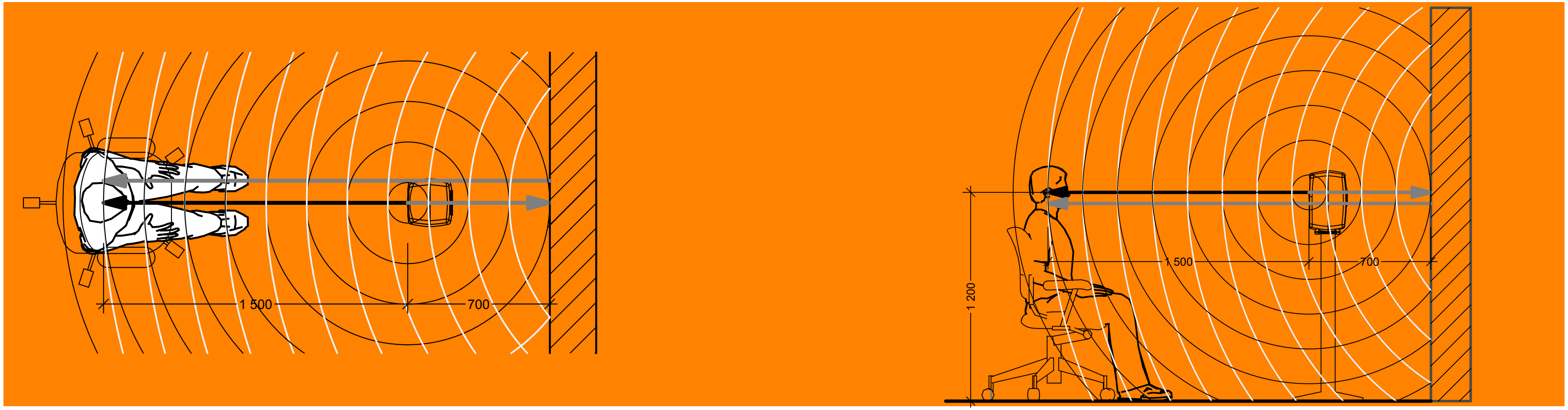
4. Loudspeaker Boundary Issues:

- Most problematic acoustic challenge
- More prominent in dry acoustic fields
  (critical impact of floor/wall interactions)

Room Modes vs. Loudspeaker/boundary effects

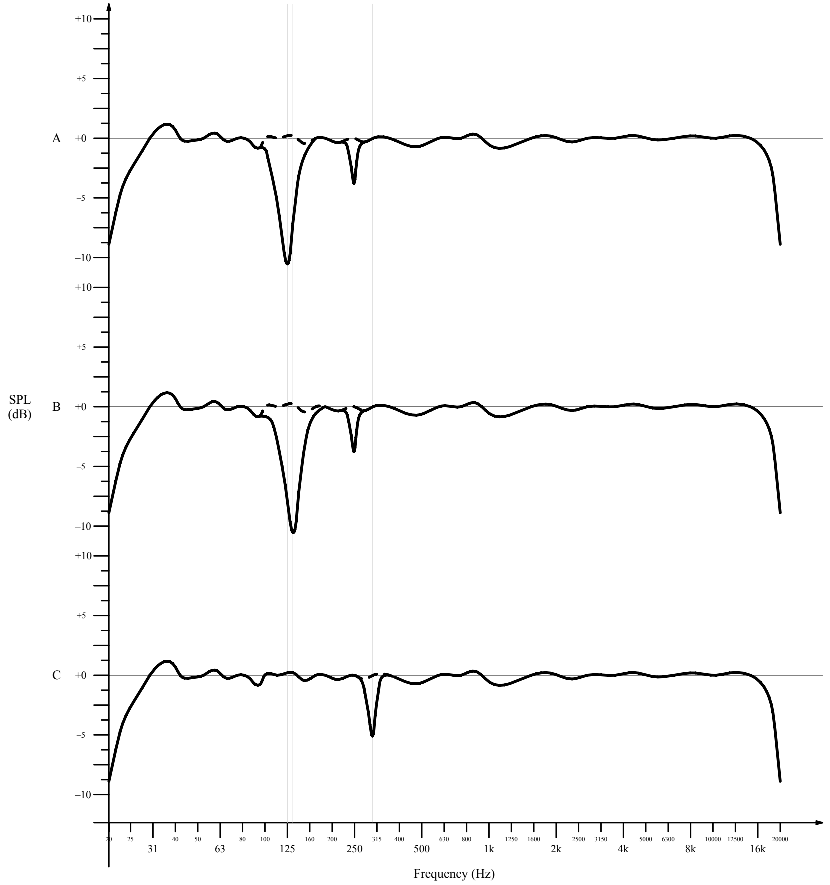
A dip in the frequency response can be caused by positioning in a resonance mode minimum or by a loudspeaker-boundary effect

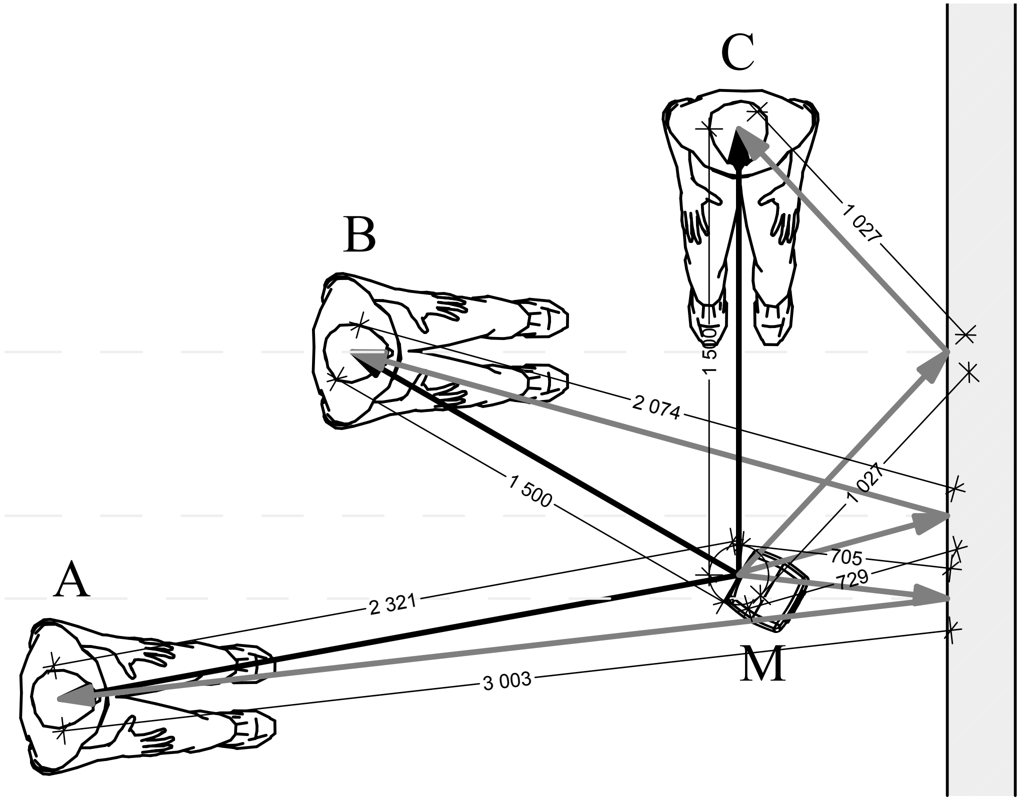
Room modes create maximum and minimum pressure zones, but loudspeaker-boundary interactions create very strong phase cancellations.



Non-minimum phase effect

Room Modes vs. Loudspeaker/boundary effects

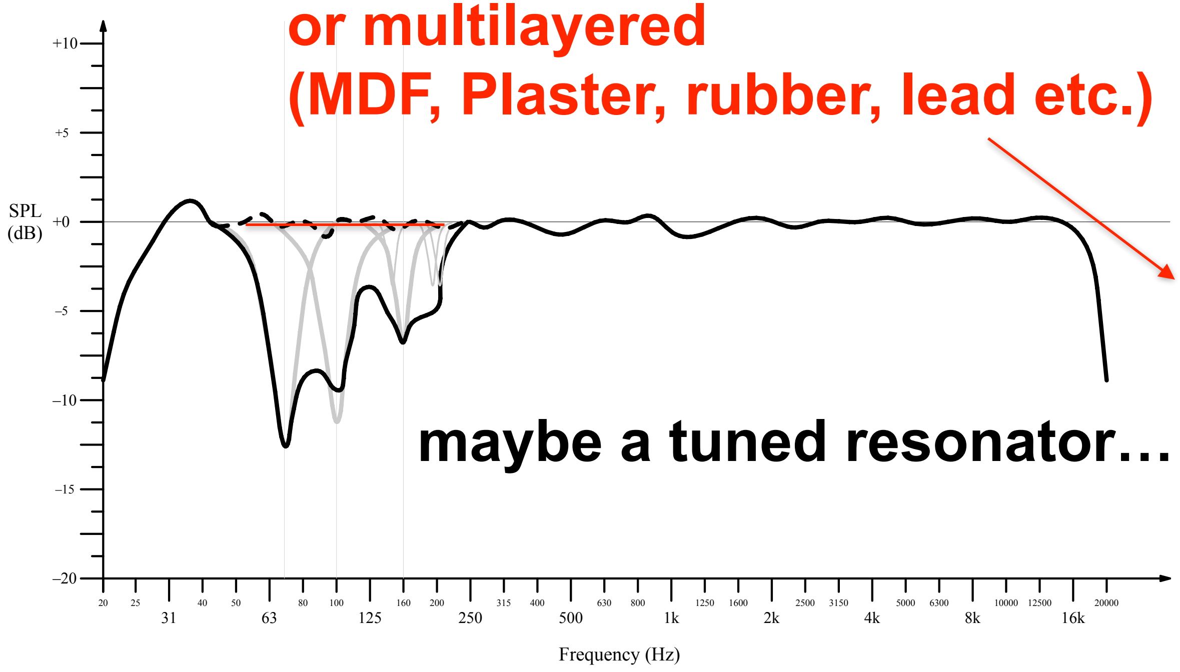




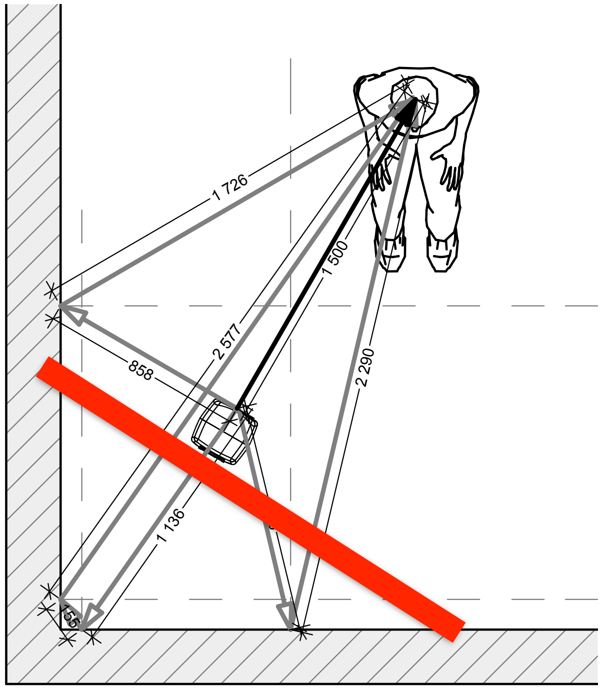
Non-minimum phase effect

Non-minimum phase effects

Solid (concrete, masonry)
or multilayered
(MDF, Plaster, rubber, lead etc.)



maybe a tuned resonator…



Non-minimum phase effect

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Active Absorption: Insights and Limitations

1. **Basic Principles**
   - **Real-time** sound detection and cancellation
   - Highly effective at **very low frequencies**
   - Immediate room response changes
   - Source-independent operation

2. **Technical Limitations**
   - **System stability issues** *(feedback challenges)*
   - Frequency-dependent effectiveness:
     - Excellent up to 80Hz
     - Increasing complexity above (>120Hz)
     - Multiple mode challenges

3. **Implementation Challenges**
   - Multiple sensor requirements
   - Room mode considerations: *Axial/Tangential/Oblique*
   - Cost escalation

4. **Key Learnings**
   - **Similar behavior to passive systems**
   - Higher costs
   - Greater instability
   - Limited broadband effectiveness *(crossover with acoustic treatment???)*

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PART 1.
LF APPLICATION: ARC DELAY

Subwoofer array design with Treble

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JAN 2025

Treble: The next generation simulation platform for room acoustics and electro-acoustics

treble

Enabling a better sounding world

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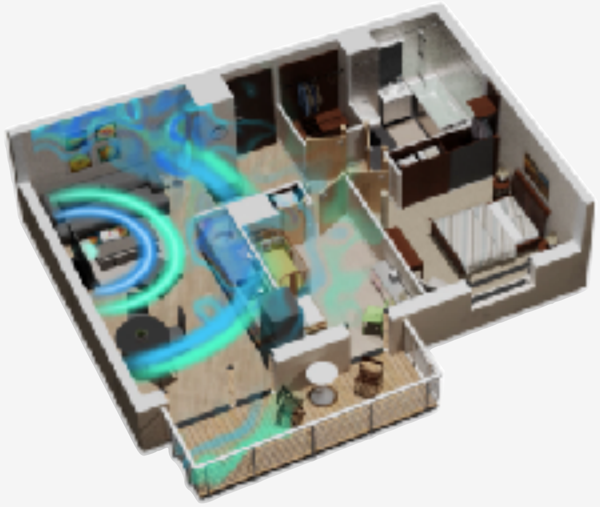
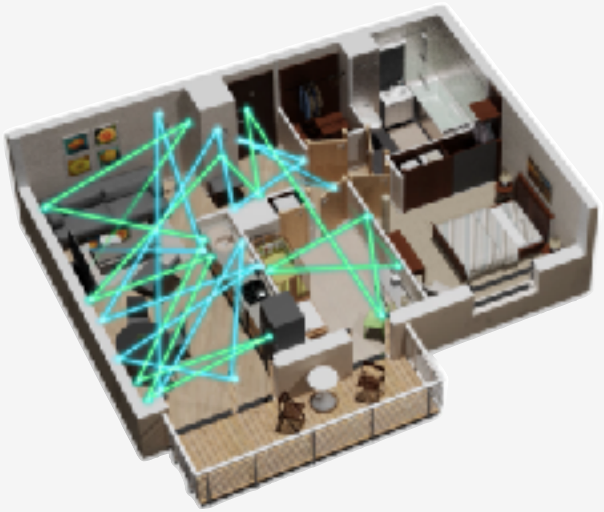
A HYBRID APPROACH TO ROOM ACOUSTIC SIMULATIONS

A paradigm shift in acoustic simulation



Efficient wave-based FEM acoustic simulations for low-mid frequencies



Phased geometrical acoustics simulations for high frequencies

Treble has developed a groundbreaking acoustic simulation and spatial audio engine. Seamlessly blend massively accelerated wave-based (FEM) modeling at low-mid frequencies with state-of-the-art phased geometrical acoustics at high frequencies for improved simulation accuracy, which in turn reduces risk, increases design quality and avoids overdesign.

Utilize Treble's proprietary geometry processing technology to enhance the efficiency of your workflows. Access a wide range of advanced features on source modeling, receiver modeling, auralization, visualization and more.

The core tech leverages recent scientific breakthroughs in applied mathematics, high performance computing and acoustics. Treble holds several patents on its proprietary simulation technology.

Treble tech is born out of high-level academic research at:

DTU Technical University of Denmark   VT VIRGINIA TECH   EPFL

BENCHMARKS & CASE STUDIES

Isolated Acoustic Phenomena

Simulation of single reflection absorption

Treble outperforms conventional GA software in accurately simulating absorbing reflections by directly solving the wave equation and applying impedance material properties, achieving superior accuracy even at low frequencies.

SEE STUDY

Simulation of single reflection diffusion

Treble excels in modeling diffuse reflections with superior accuracy compared to conventional GA software, leveraging direct wave equation solutions to capture complex sound scattering effects realistically.

SEE STUDY

Simulation of diffraction

Treble accurately simulates diffraction by directly solving the wave equation, outperforming traditional GA software, particularly in complex scenarios like large barriers or finite diffracting bodies.

SEE RS5 STUDY SEE RS6 STUDY

Simulation of seat dip effect

Treble accurately simulates seat dip effects, common e.g. in performance halls, by solving the wave equation with correct surface impedance data, outperforming GA software in modeling complex diffraction behavior.

SEE STUDY

Create new material

MATERIAL NAME

MATERIAL CATEGORY

Default scattering 0,3

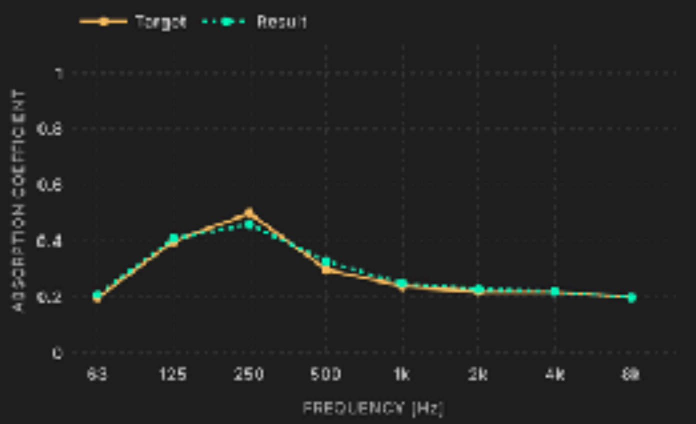
MATERIAL DESCRIPTION (OPTIONAL)

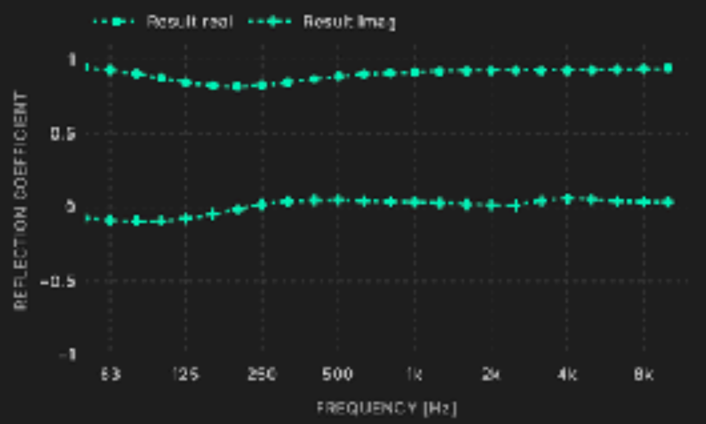
Material import / input | Porous material builder (Beta)

Full octave absorption | Surface impedance | Reflection coefficient

Absorption coefficient (Random Incidence) — Upload file

Frequency (Hz)	63	125	250	500	1k	2k	4k	8k
Target	0,2	0,4	0,5	0,3	0,24	0,22	0,22	0,20
Result	0.21	0.41	0.46	0.33	0.25	0.23	0.22	0.2





Share with organization

Edit | Create material

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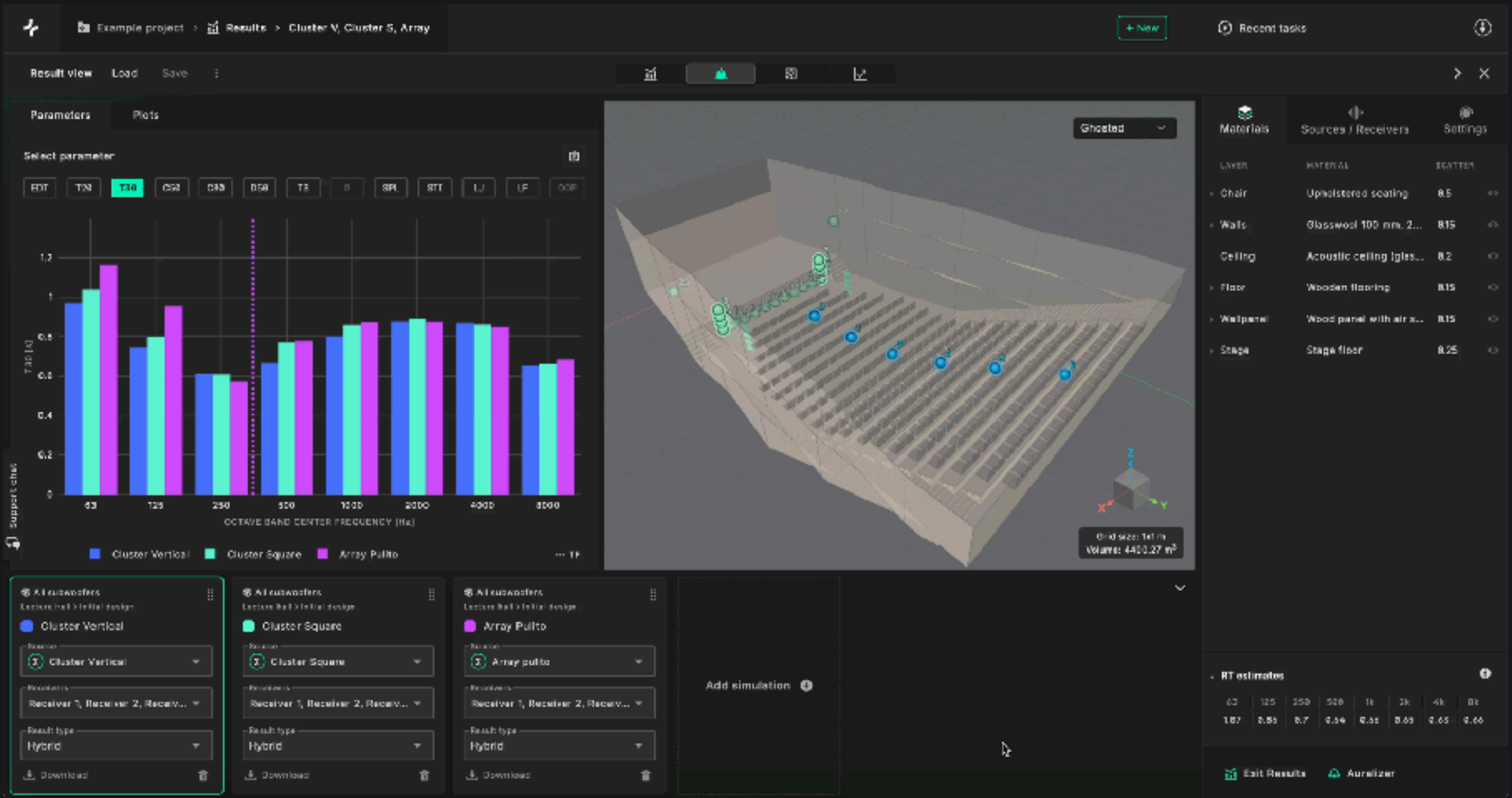
Subwoofer Array Design



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Subwoofer Array Design: Applying the delay

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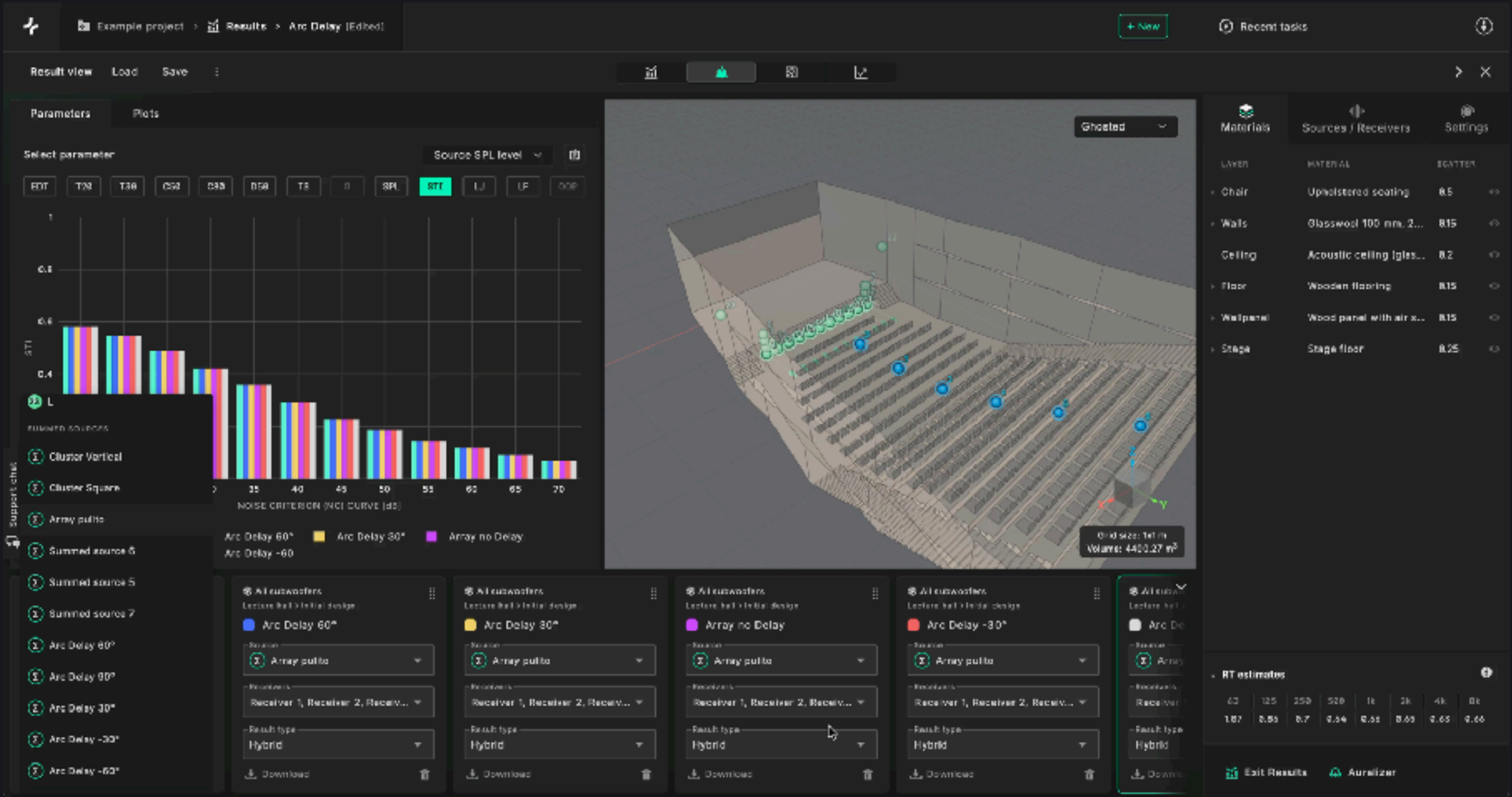
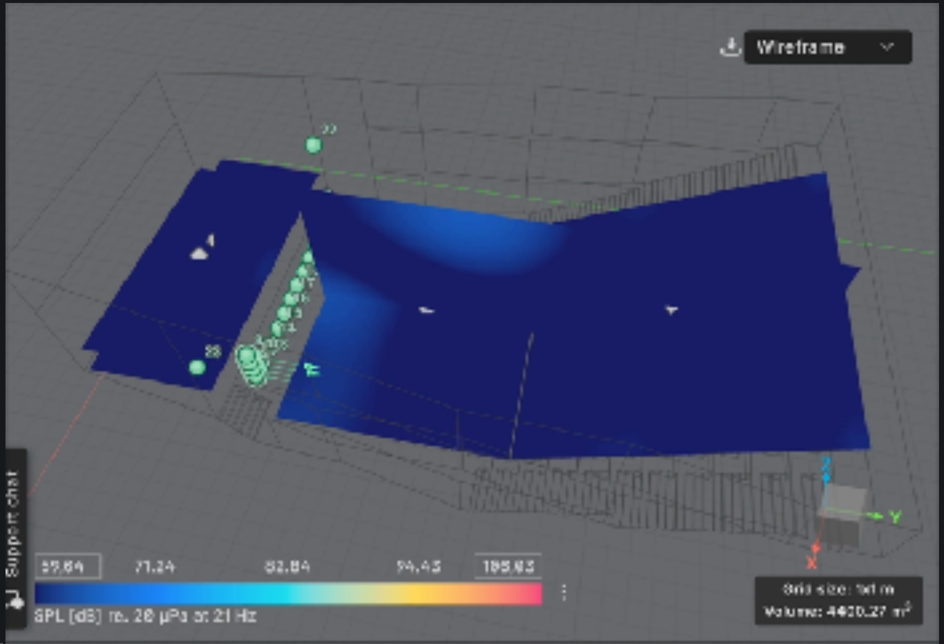
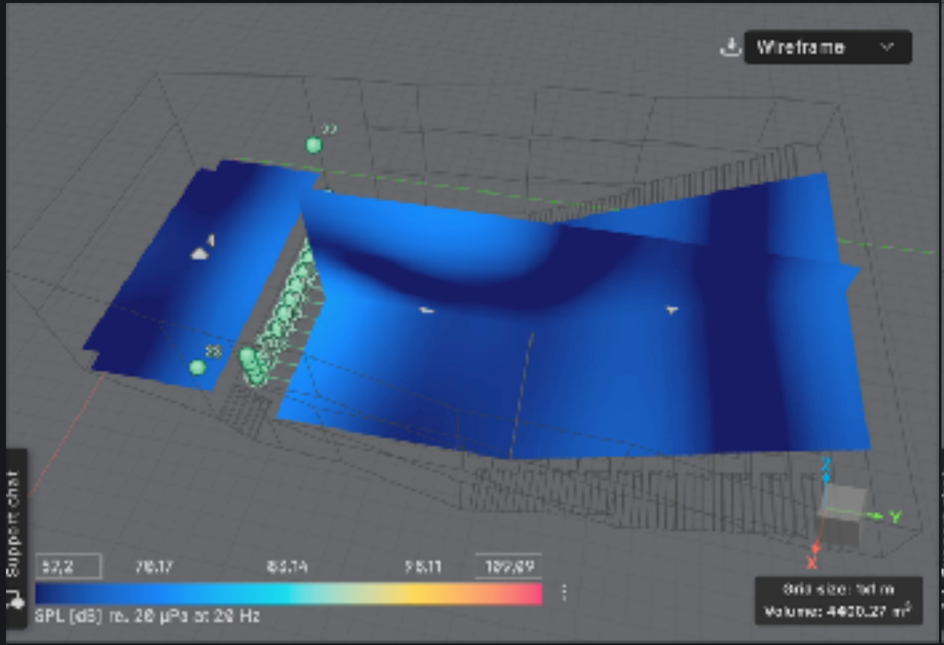


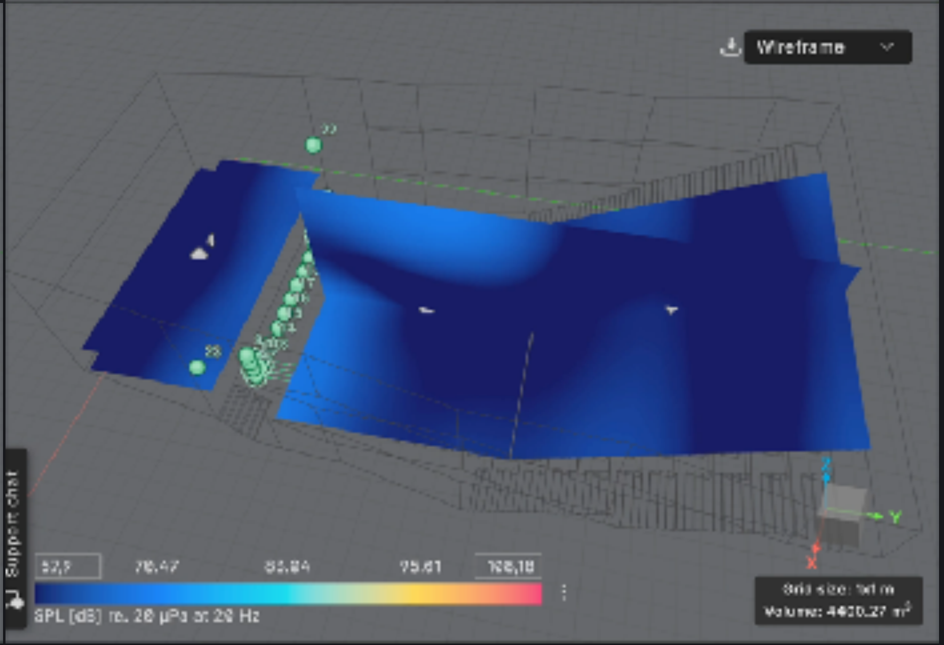
Cluster Vertical



Array



Cluster Square



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Subwoofer Array Design

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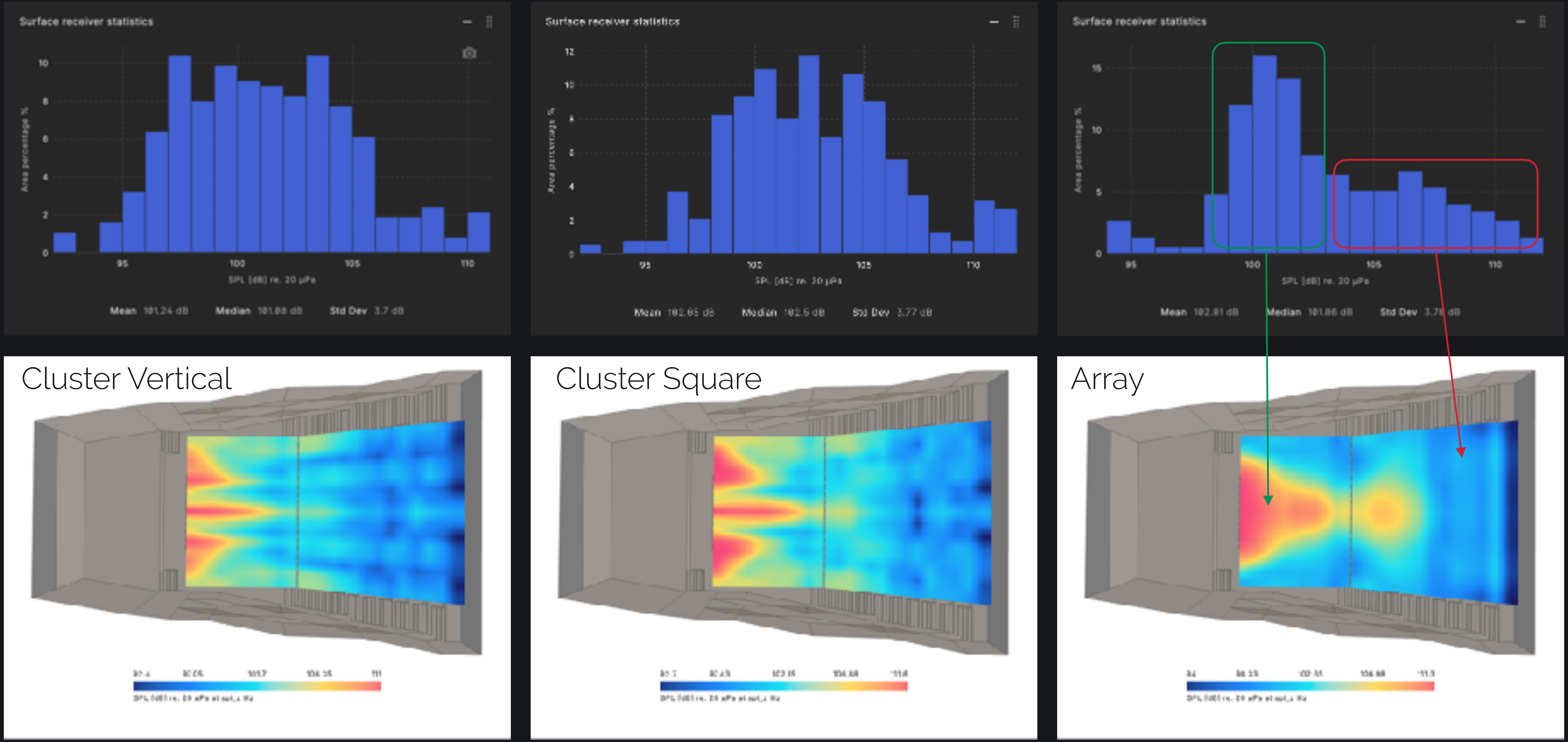
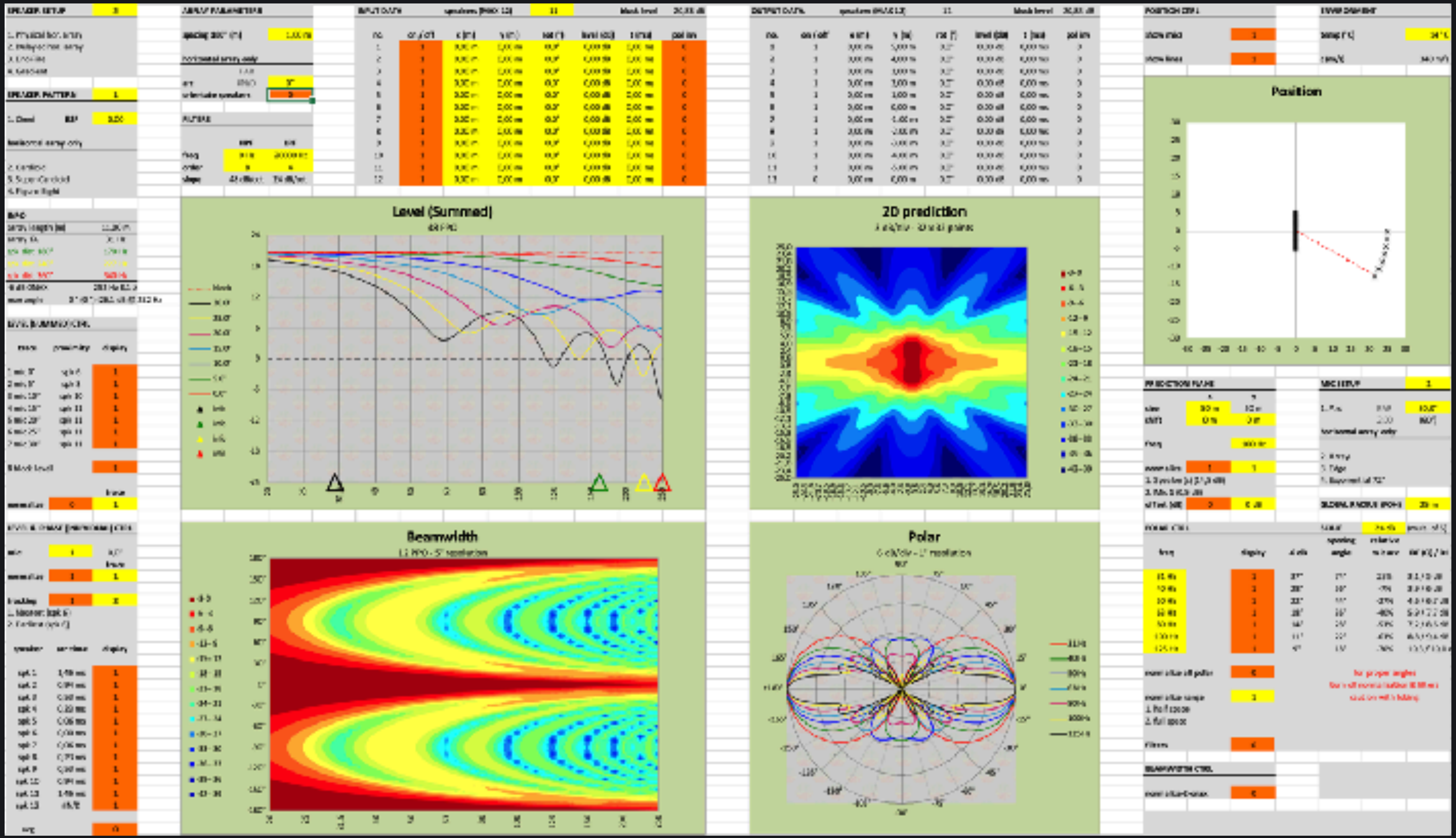
63 Hz



S.A.D. V1.10 BY MERLIJN VAN VEEN



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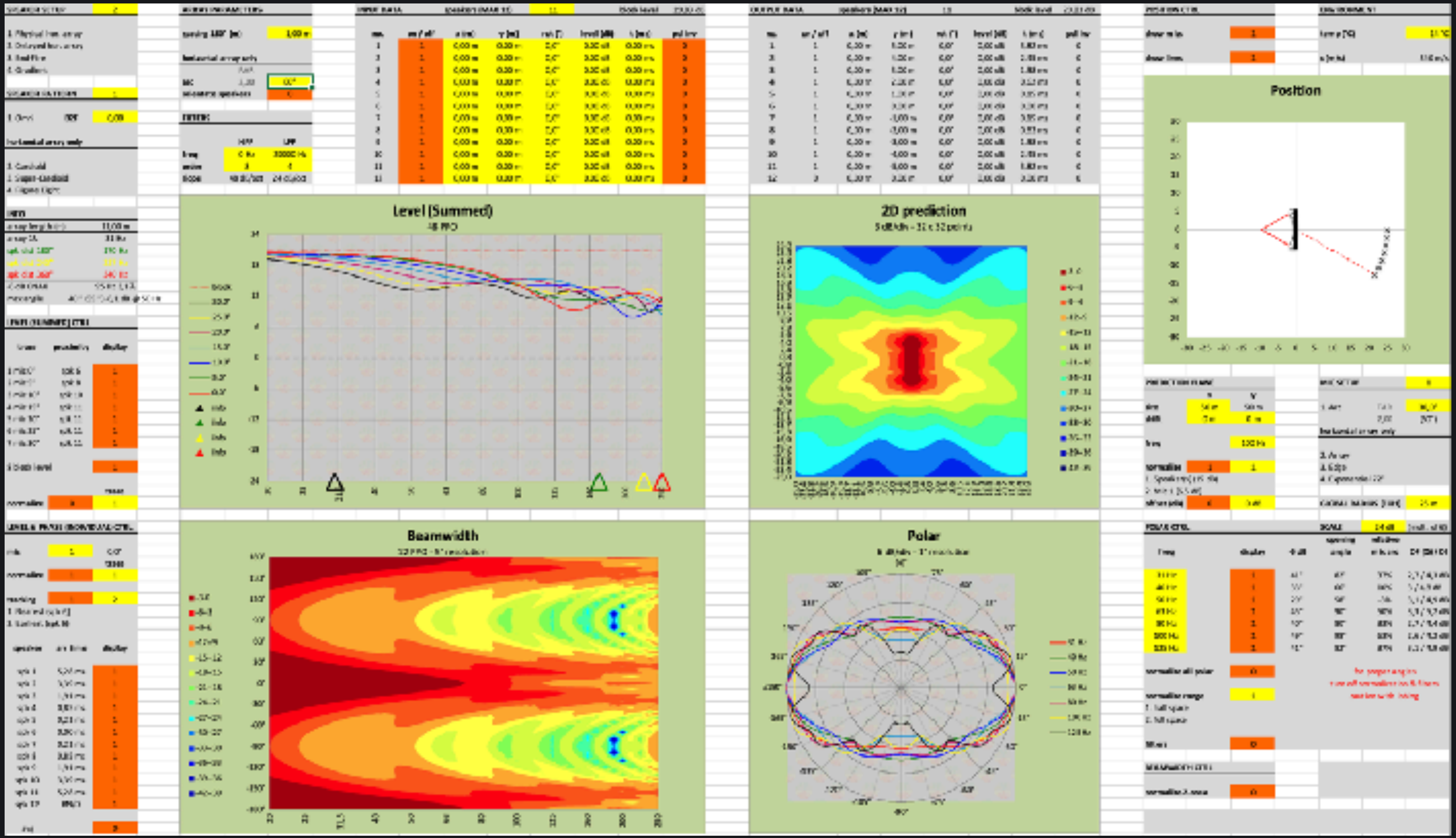

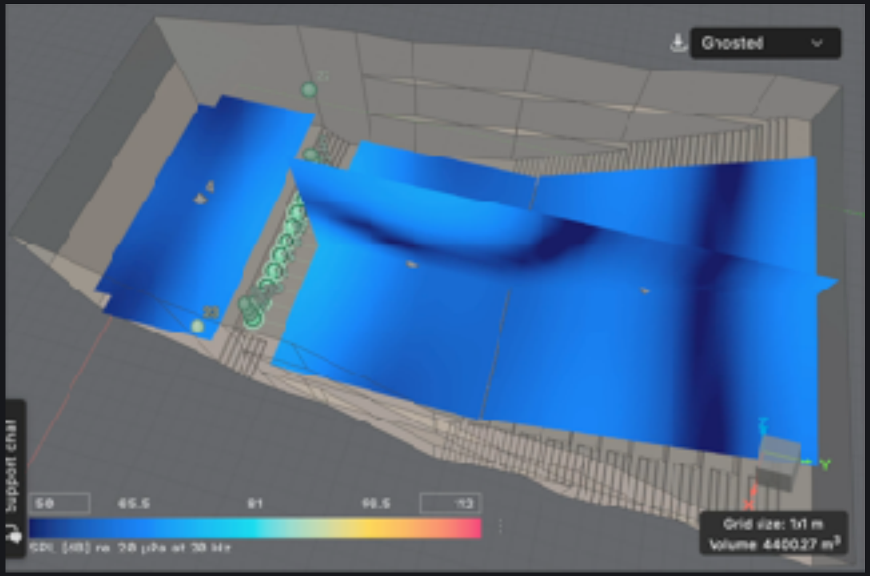
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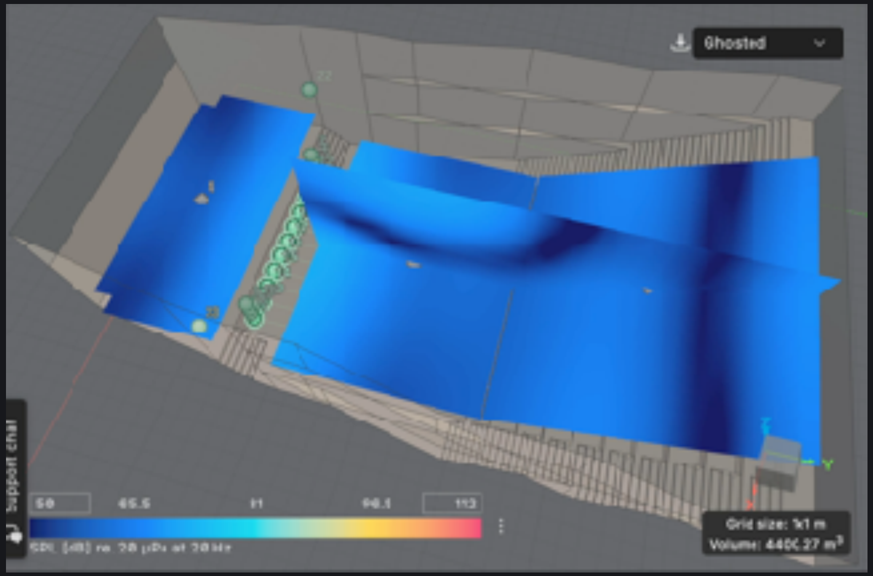
0°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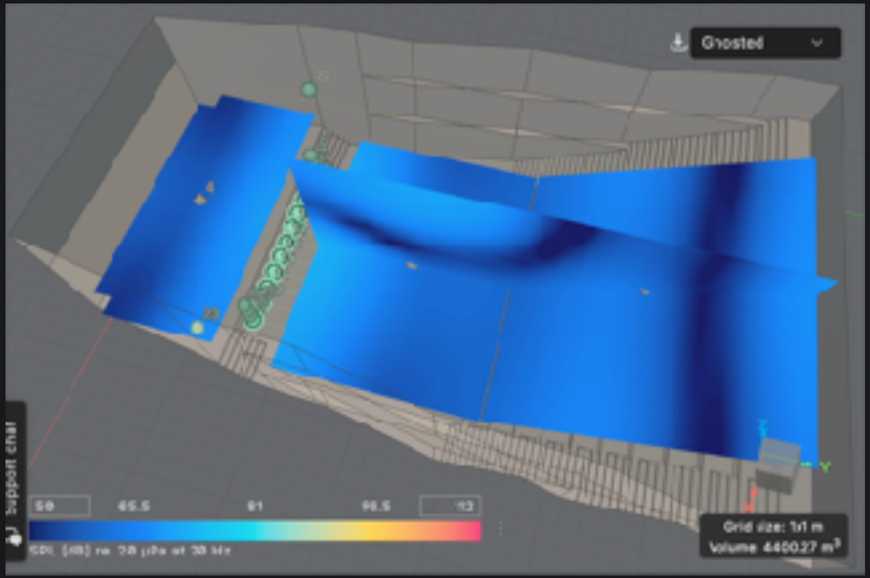
60°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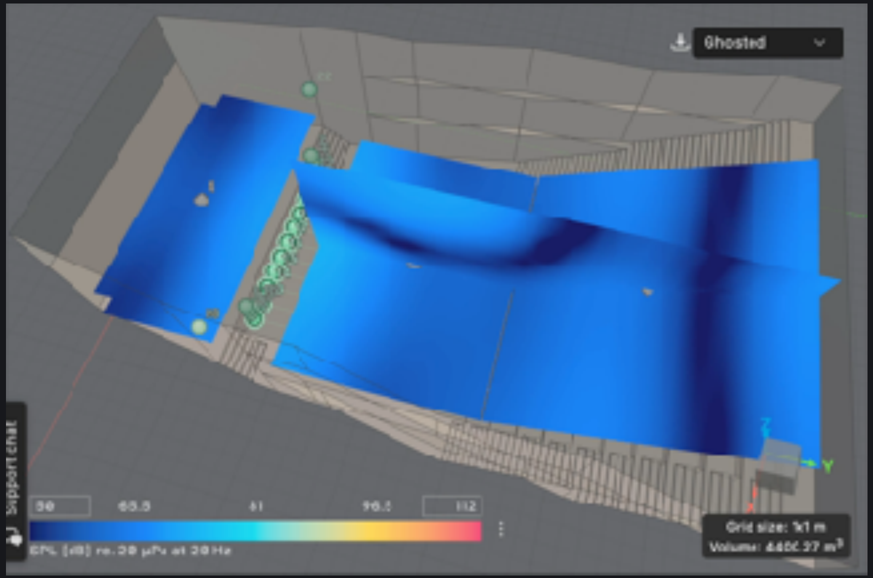
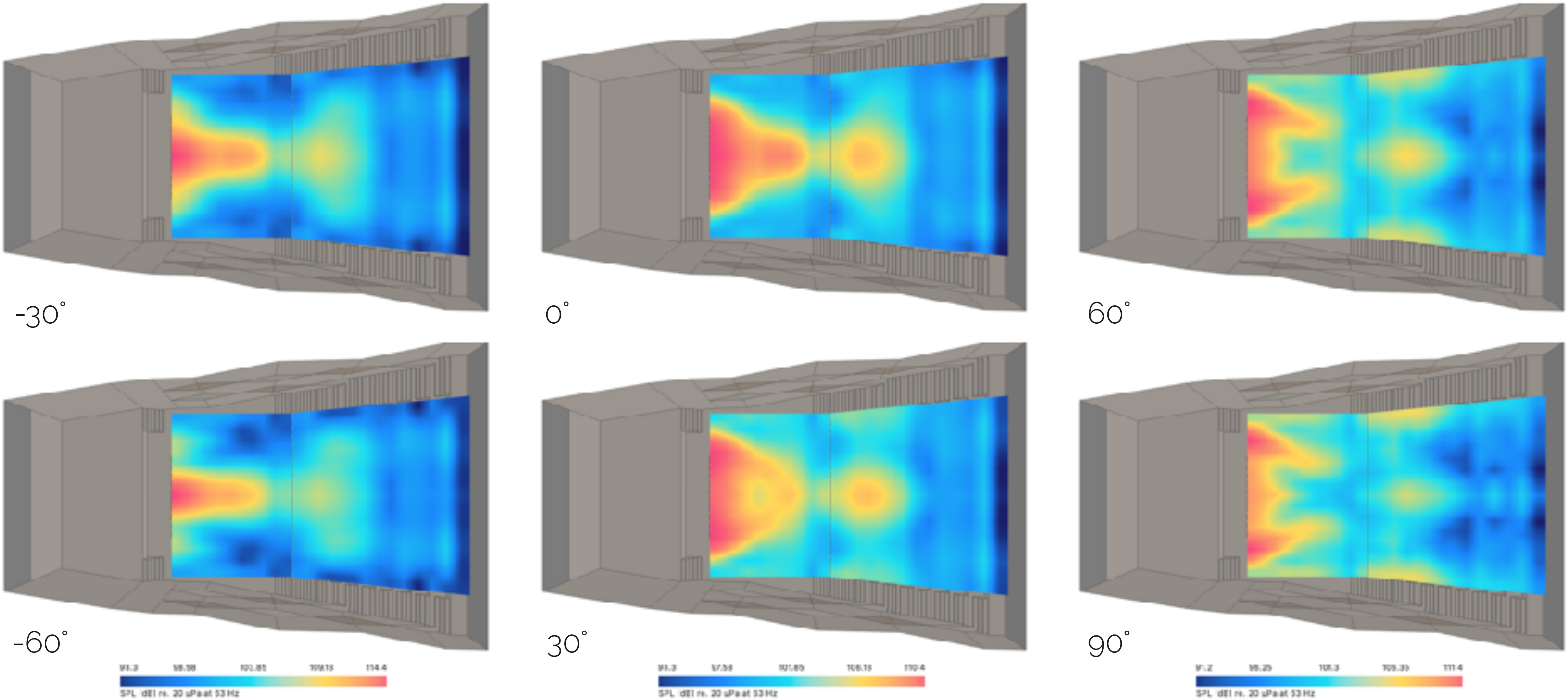
30°

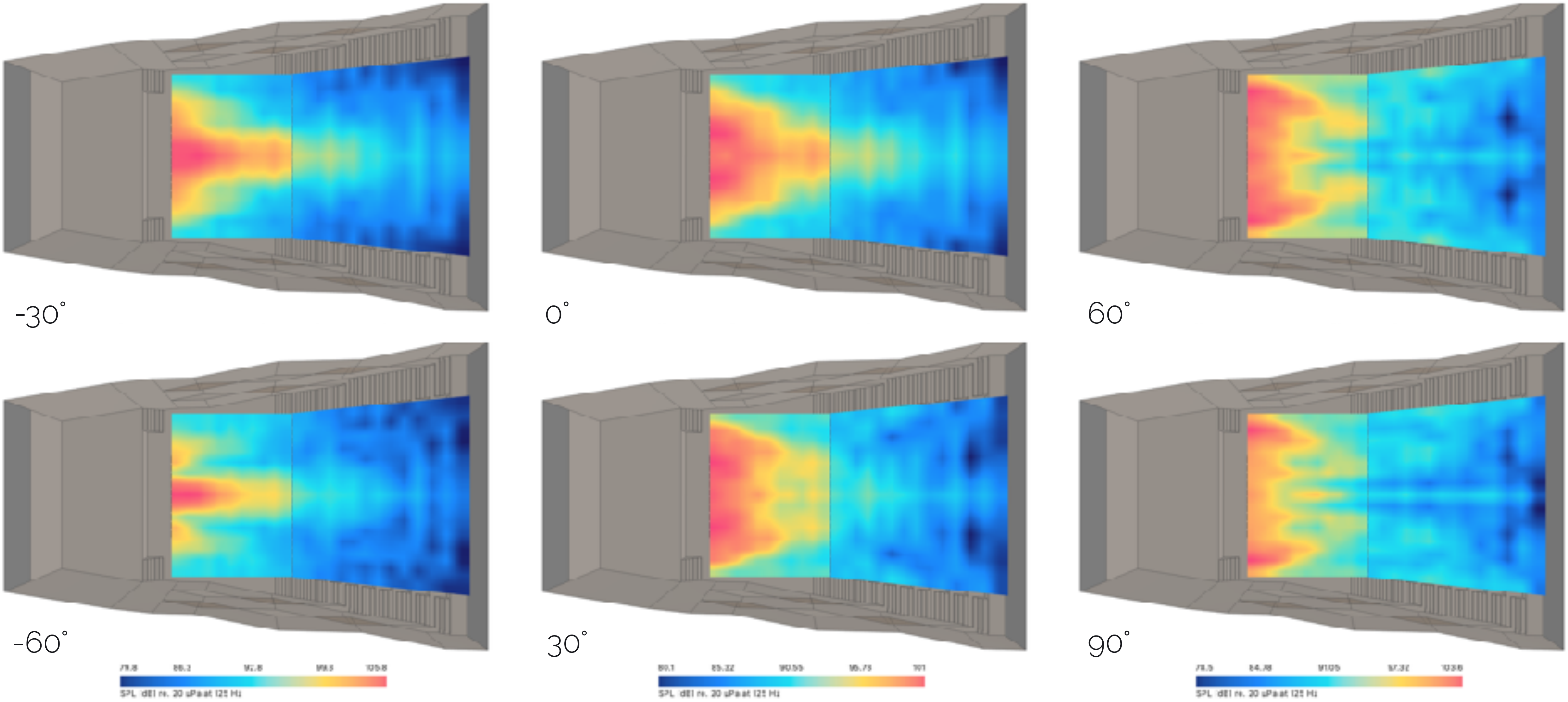

Ghosted
Grid size: 1x1 m

-60°

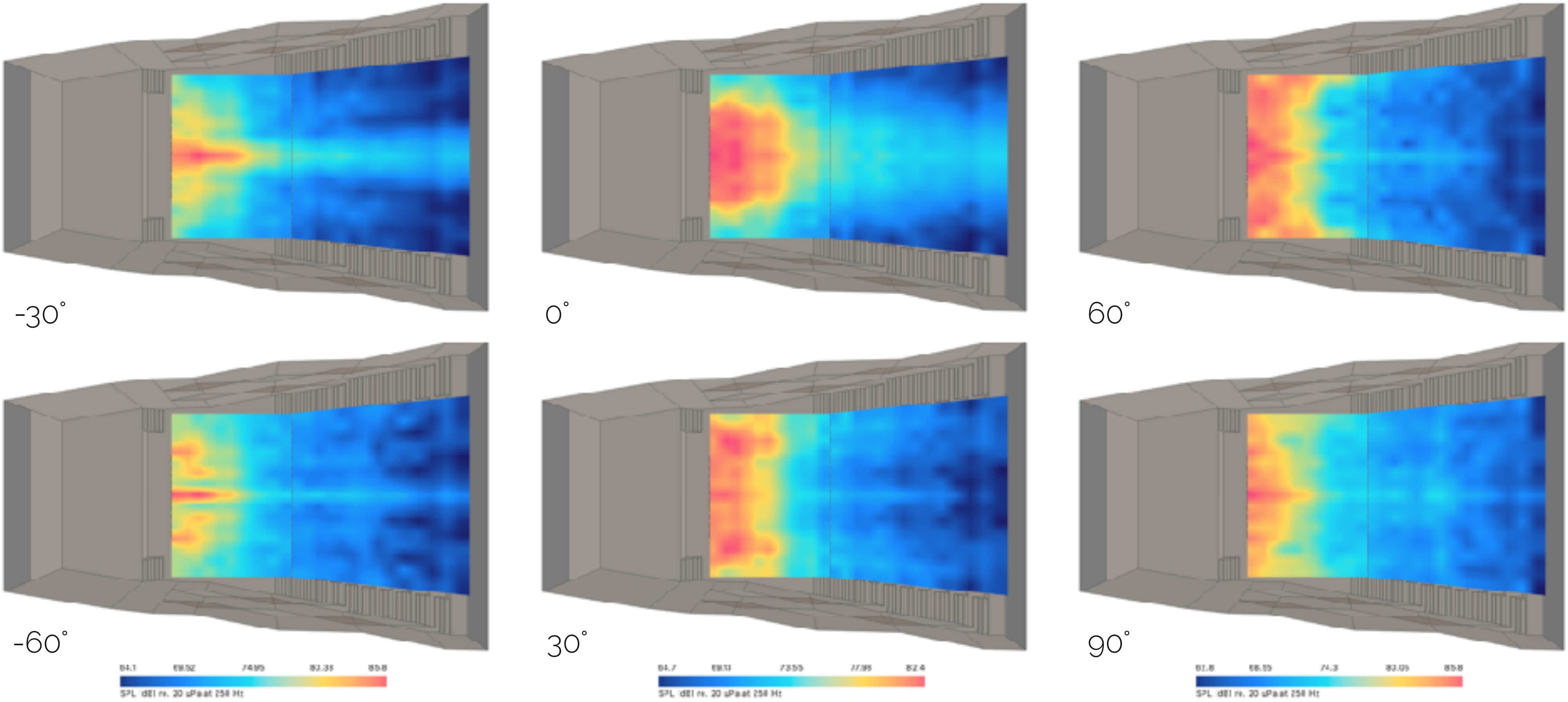
63 Hz



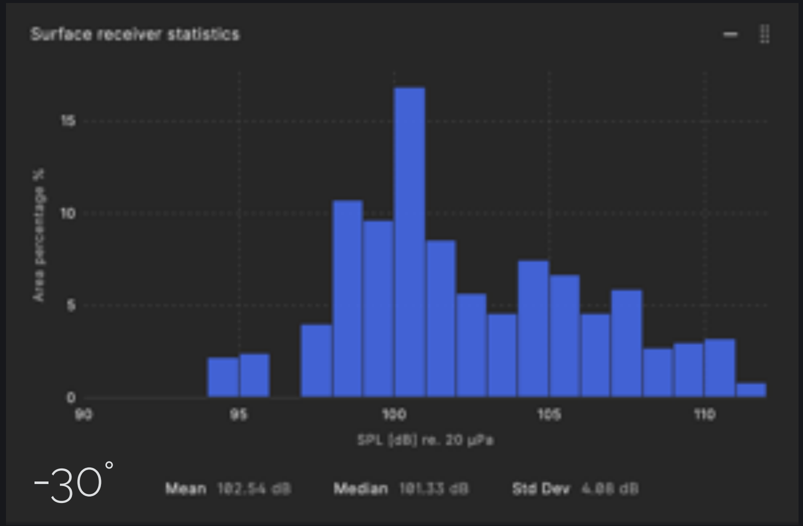
125 Hz

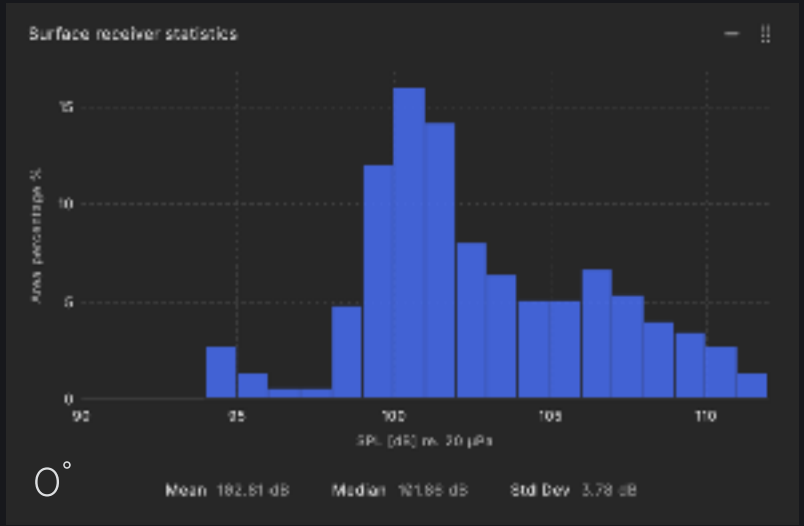


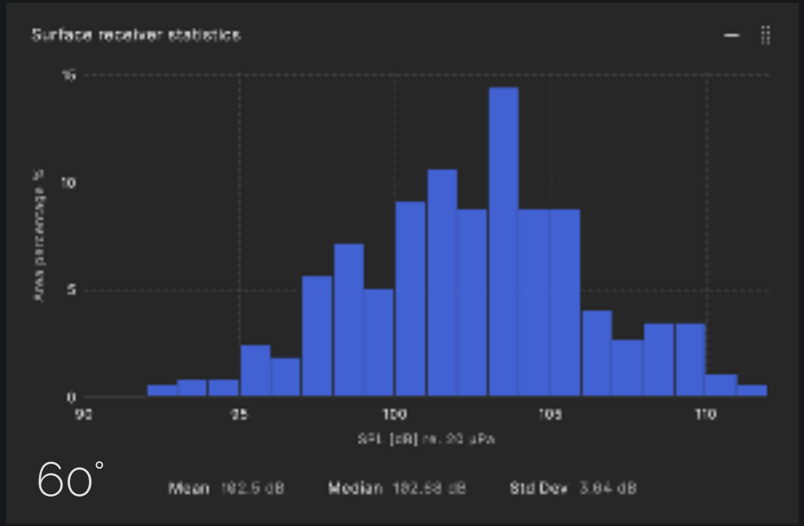
250 Hz

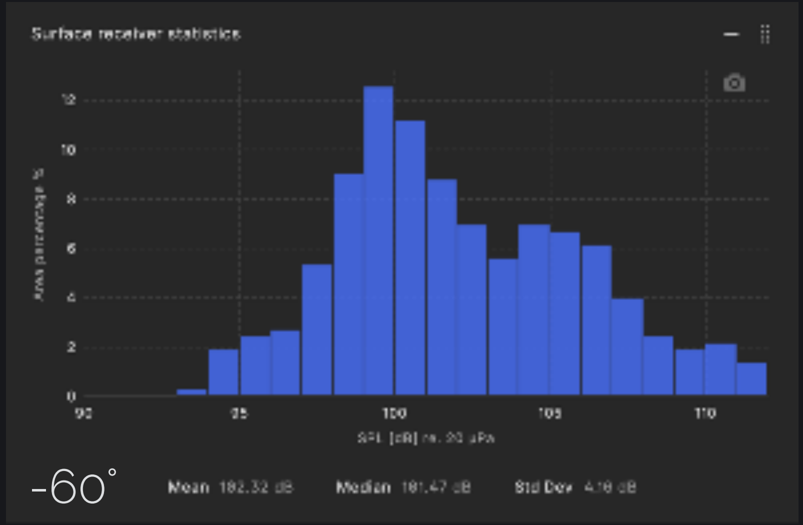


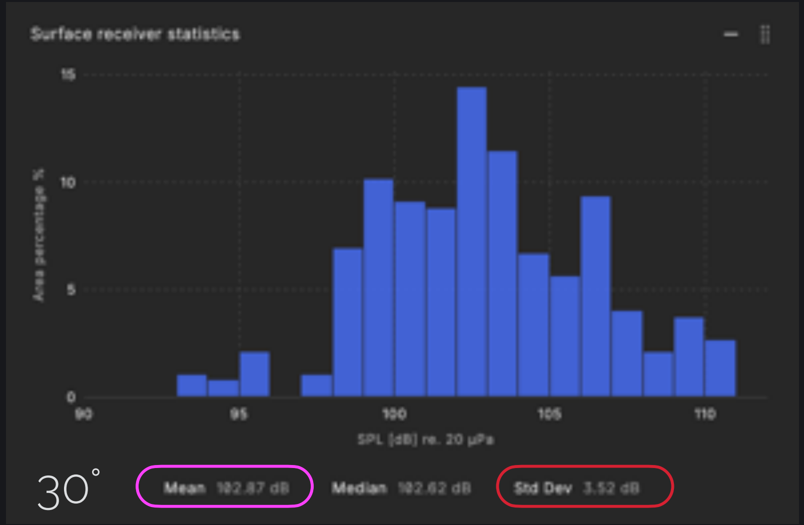
Total SPL

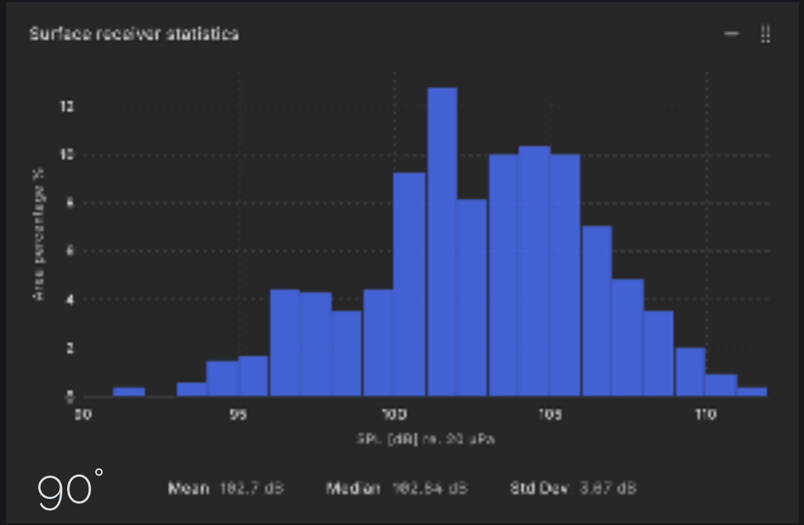

Surface receiver statistics
Area percentage %
SPL [dB] re. 20 µPa
-30°
Mean 102.54 dB
Median 101.33 dB
Std Dev 4.08 dB


Surface receiver statistics
Area percentage %
SPL [dB] re. 20 µPa
0°
Mean 102.81 dB
Median 101.86 dB
Std Dev 3.78 dB


Surface receiver statistics
Area percentage %
SPL [dB] re. 20 µPa
60°
Mean 102.5 dB
Median 102.68 dB
Std Dev 3.84 dB


Surface receiver statistics
Area percentage %
SPL [dB] re. 20 µPa
-60°
Mean 102.32 dB
Median 101.47 dB
Std Dev 4.18 dB


Surface receiver statistics
Area percentage %
SPL [dB] re. 20 µPa
30°
Mean 102.87 dB
Median 102.62 dB
Std Dev 3.52 dB


Surface receiver statistics
Area percentage %
SPL [dB] re. 20 µPa
90°
Mean 102.7 dB
Median 102.84 dB
Std Dev 3.87 dB

Arc delay optimization: beyond polar patterns

TRADITIONAL APPROACH

- Polar patterns show source directivity

TREBLE WAVE SIMULATION

- shows room response to that directivity
- Arc delay example:
- Opening the arc → SPL **Std Dev** decreases ✓
- Beyond critical angle → SPL **Std Dev** increases again ✗
- Visual feedback: lateral wall interactions emerge

Result: optimize coverage angle for *this specific room*, not just theoretical pattern

STUDIO SOUND SERVICE

PART 2.
LF SIMULATION IN A SMALL ROOM

Where Control Meets Precision

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Small Rooms: The Luxury of Modal Control

THE SMALL ROOM ADVANTAGE

Below Schroeder Frequency (~350Hz):

- Individual modes are audible
- We can count them
- We can measure them
- **We can kill them (one by one!!!)**

OUR WEAPON

- Wave-based simulation (FEM/BEM)
- *(?) Precise impedance control*
- Targeted treatment
- Mathematical certainty

Result: ±5% accuracy

Critical insight:
*"In small rooms, we are **gods**"*

From Empty Box to Validated Model


Conference Paper | PDF Available

A simulation test bench for decay times in room acoustics

October 2018

Conference: COMSOL Conference 2018 · At: Lausanne (Switzerland)

Authors:

Roberto Magalotti, Bowers & Wilkins
Valentina Cardinali, B&C Speakers

- Inverse problem: From MT60 to impedance
- 4 modes = 4 unknown = 4 impedance
- Modal participation factors (ε)
- Process:
  Measure MT60 → Calculate ε → Assign Z
- *Works for 6 surfaces, doesn't scale to 100*
- *Controlled materials*
- *No aging, no surprises*

2025 ISE CEDIA Convention

We used the procedure from Roberto Magalotti and Valentina Cardinali's paper:
"A simulation test bench for decay times in room acoustic"

to indirectly estimate the acoustic impedance of the walls with **COMSOL®**

and we calculated it using a **Mathematica®** tool

Method - Notes

MT60 formula:
4 equations, 4 β

$$MT_{60,N} = \frac{6\ln(10)}{c}\frac{V}{\sum_j \epsilon_{N_j}\beta_j S_j}$$

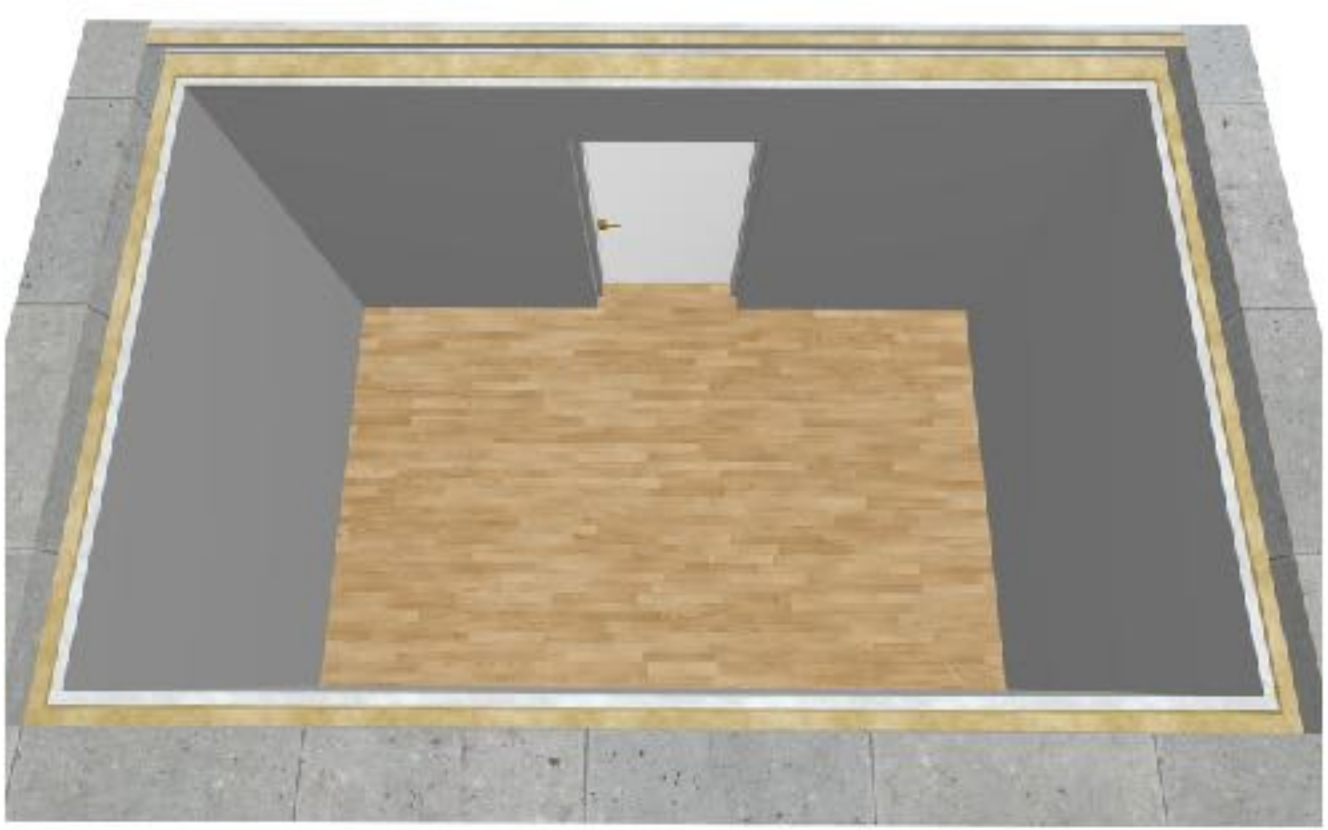
Notes on situation complexity:

1. MT60 evaluation was complicated by the empty room being highly reflective, but not as much at low frequencies due to the resonant behavior of drywall

2. The room has small dimensions and similar width and height, creating degenerate modes that are difficult to isolate in the FR

Additional note: in the final result, this calibration was equally well approximated by an average β calculated from this calibration

Method - Variables

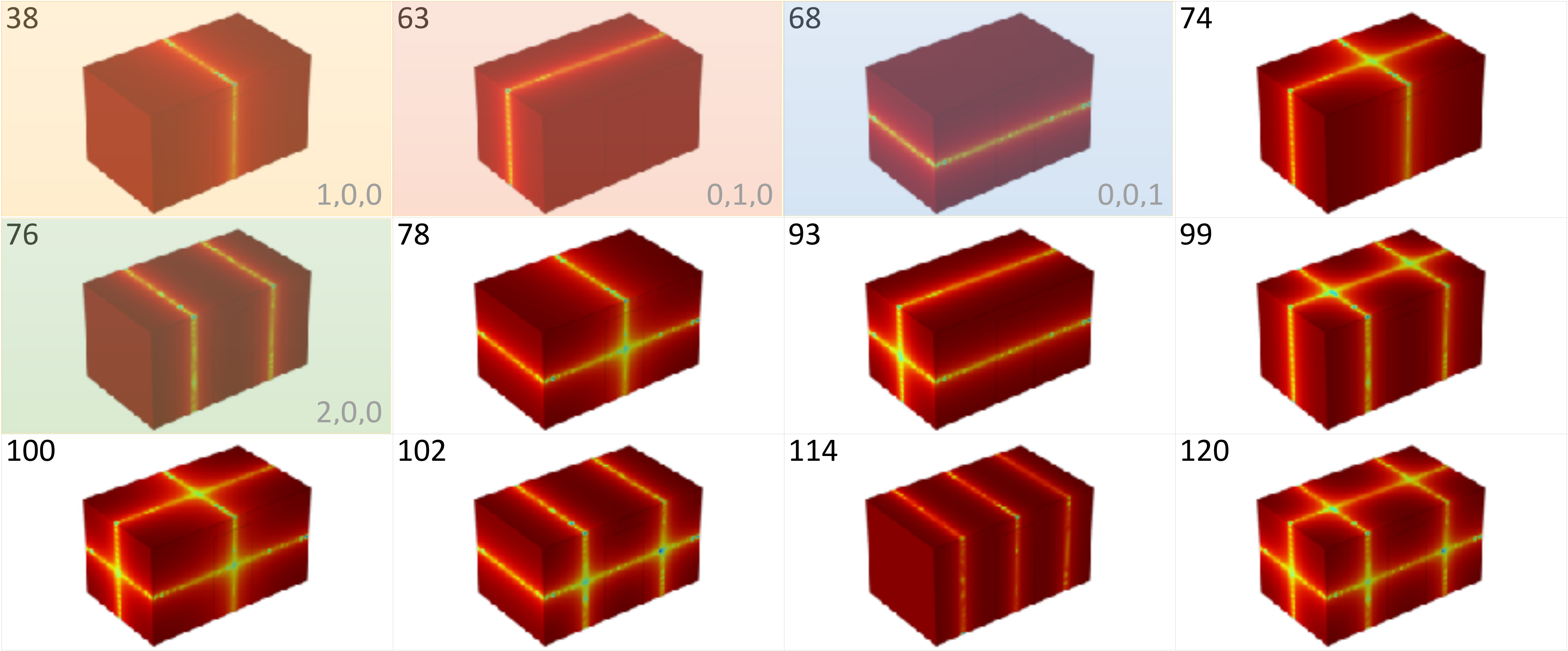


We determined the number of unknown variables in the room (different impedances):

- 3 false walls against concrete
- ceiling and floor
- 1 door
- 1 drywall partition

We need to choose 4 room mode in order to have
4 equations and
4 unknown variables

Method - Room modes



Method - Factor ε

$$\epsilon_{N_j} = \langle {\phi_N}^2 / \Lambda_N^0 \rangle_{S_j}$$

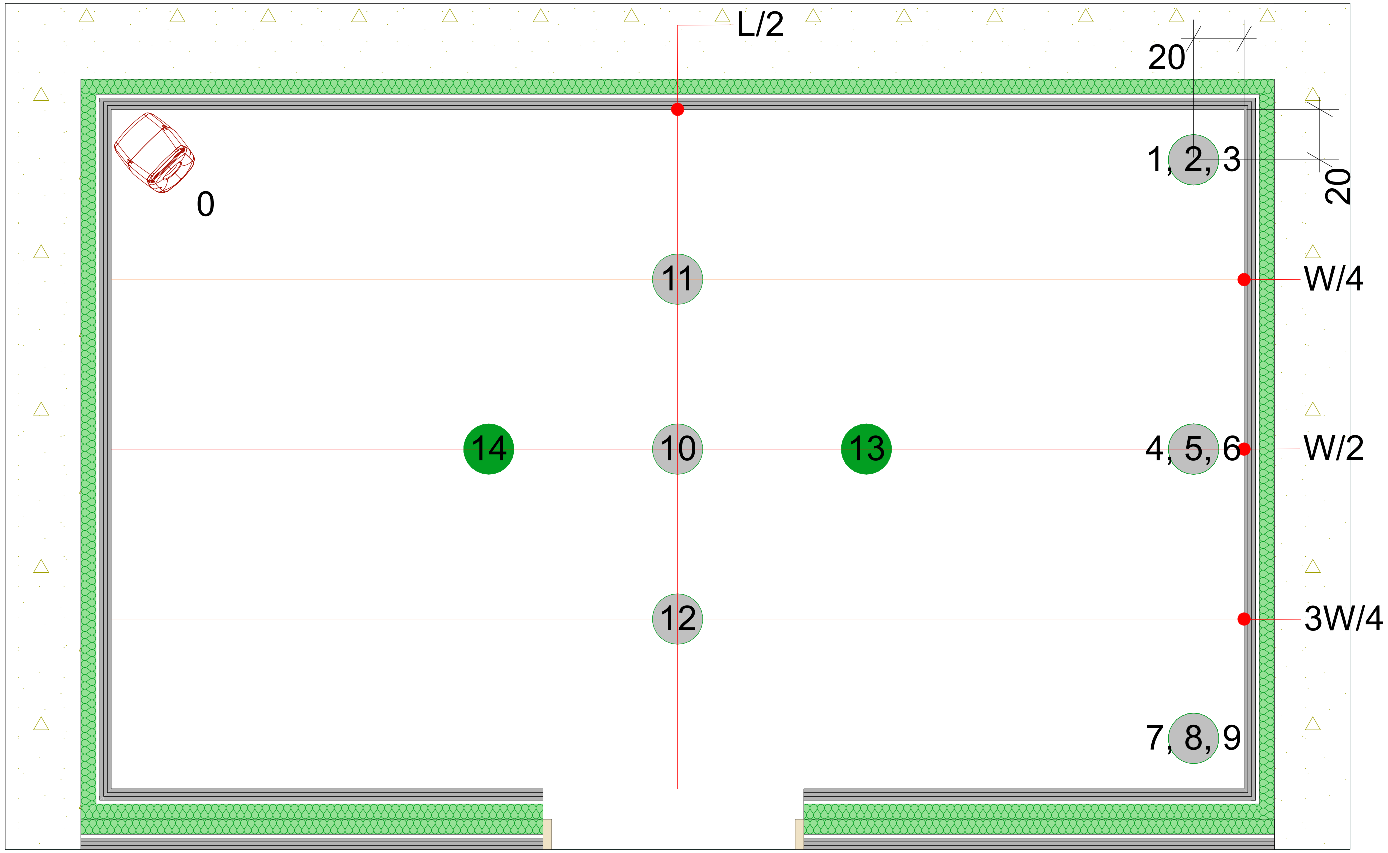
Eigenfrequency (Hz)	epsPAV_N	epsSOFF_N	epsRETRO_N	epsLATSX_N	epsLATDX_N	epsFRONTE_N	epsPORTA_N
4.0014E-6-4.0714E-7i	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
38.216	1.0000	1.0000	1.0000	2.0000	2.0000	1.2423	0.063866
53.722	1.0000	1.0000	2.0000	1.0000	1.0000	2.0000	2.0000
57.988	2.0000	2.0000	1.0000	1.0000	1.0000	1.0353	0.86918
74.304	1.0000	1.0000	2.0000	2.0000	2.0000	2.4847	0.18779
76.438	1.0000	1.0000	1.0000	2.0000	2.0000	0.82456	1.6550
77.994	2.0000	2.0000	1.0000	2.0000	2.0000	1.2458	0.061522
93.182	2.0001	2.0001	2.0001	1.0000	0.99999	2.0706	1.7384
99.518	1.0000	0.99999	2.0001	2.0001	2.0001	1.6482	3.3720
100.72	2.0001	2.0001	2.0001	2.0000	2.0000	2.4914	0.10305
102.30	2.0001	2.0001	0.99998	2.0001	2.0001	0.88296	1.4377
114.56	0.99999	0.99999	0.99999	2.0002	2.0002	1.0886	0.66858
120.53	2.0002	2.0002	2.0002	2.0002	2.0002	1.7660	2.8755
127.45	0.99996	0.99999	2.0003	0.99999	0.99997	2.0003	2.0003
131.18	0.99998	0.99997	2.0002	2.0004	2.0004	2.1775	1.3573
133.08	0.99998	0.99998	2.0004	2.0000	2.0001	2.4851	0.18783
133.30	2.0002	2.0002	0.99998	2.0004	2.0004	1.1122	0.58347
136.98	2.0004	2.0004	0.99998	0.99992	0.99995	1.0244	0.90876
141.26	2.0006	2.0005	0.99996	2.0000	2.0000	1.2446	0.065387
144.45	2.0002	2.0002	2.0005	0.99997	0.99997	2.0711	1.7308
147.76	2.0003	2.0003	2.0003	2.0006	2.0005	2.2247	1.1610
148.62	0.99995	0.99999	2.0006	2.0004	2.0003	1.6496	3.3129
149.42	2.0003	2.0002	2.0006	2.0000	2.0001	2.4921	0.16310
150.18	2.0006	2.0008	2.0002	0.99995	0.99991	2.0491	1.8178
152.88	0.99994	0.99996	0.99987	2.0006	2.0008	0.98133	1.0375
154.97	2.0007	2.0007	2.0009	1.9999	2.0001	2.4886	0.17070
156.00	2.0007	2.0007	0.99995	2.0003	2.0004	0.96499	1.5048
163.44	2.0003	2.0003	2.0009	2.0005	2.0004	1.7066	2.8765
165.64	0.99990	0.99990	2.0003	2.0009	2.0010	1.9828	2.0654
167.33	2.0004	2.0003	0.99979	2.0010	2.0009	1.0278	0.89552
168.52	2.0010	2.0010	2.0002	2.0004	2.0004	1.7302	3.0100
171.45	0.99994	0.99989	2.0009	2.0008	2.0009	2.1783	1.3378
177.89	2.0012	2.0011	0.99986	2.0009	2.0009	1.1048	0.60765
179.08	2.0004	2.0003	2.0004	2.0013	2.0013	2.0557	1.7931
184.45	2.0009	2.0004	2.0012	2.0010	2.0011	2.2258	1.1616
186.38	2.0013	2.0014	2.0012	1.0002	0.99953	2.0501	1.8195
188.97	2.0015	2.0014	2.0003	2.0012	2.0010	2.2102	1.2156

We built the model in COMSOL® and performed eigenfrequency analysis to determine the modal participation factor ε of each surface.
We did not rely on the uniform rectangular room model because we had a door, which represents an impedance non-uniformity.
Surfaces have a higher participation factor where the mode has maximum pressure points.

ε represents a form of modal intensity on the surface

- Modal participation factor of the surface
- ε is a two-index factor Nj that relates to a mode and a surface: each surface of the room contributes to modifying the single mode with its own epsilon weight.
- Indeed, in a perfectly rectangular room these values follow simple patterns
- for example, the door that is halfway along the long side doesn't contribute at all to the main mode because at that point the pressure is zero, while it does contribute to other modes.

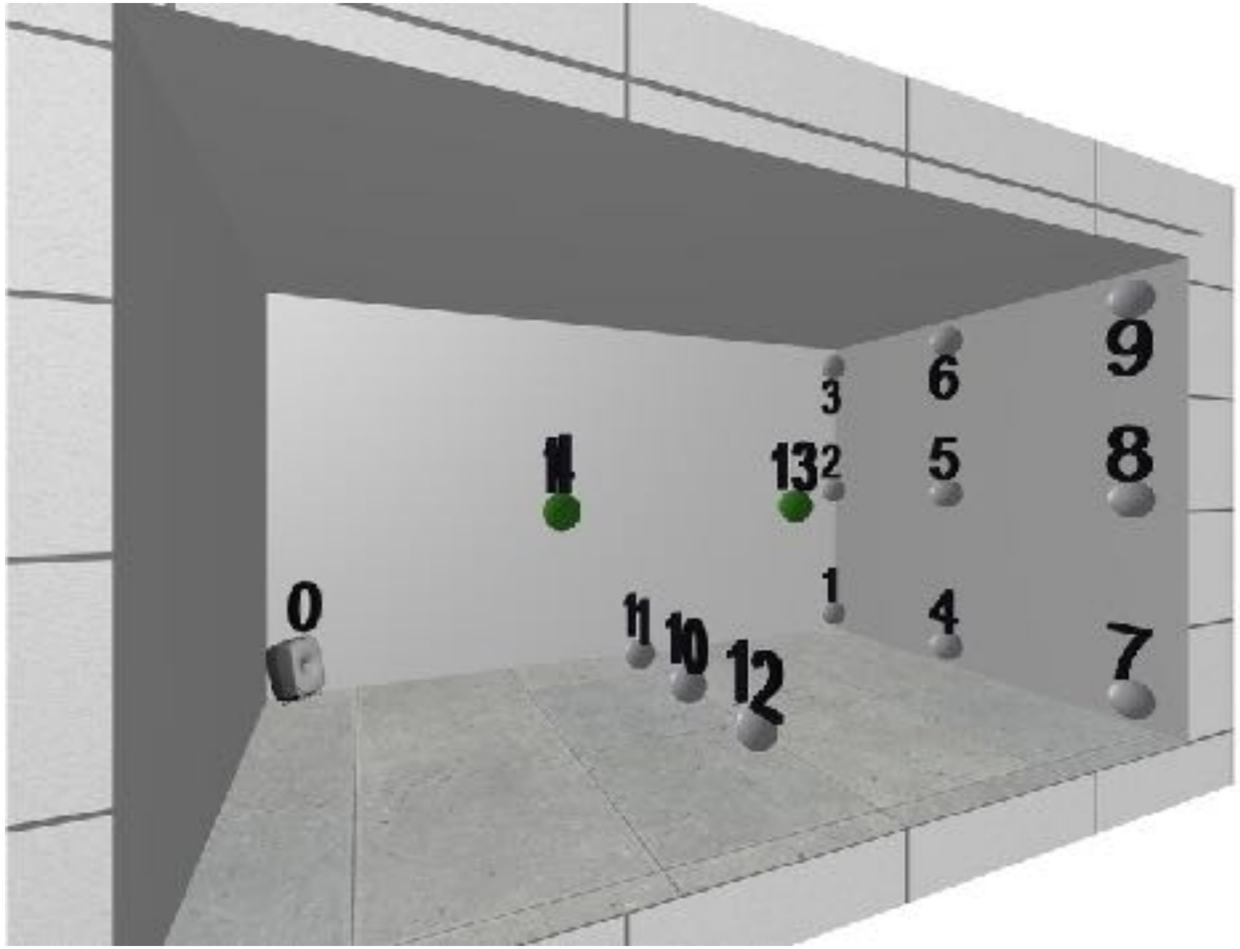
Measurements in the SSStudio



1. We chose to place the source in a corner in order to excite all room modes

2. We decided to place the measurement points in strategic positions to get a complete representation of the first modes for room calibration.

Measurements in the SSStudio



Points were selected

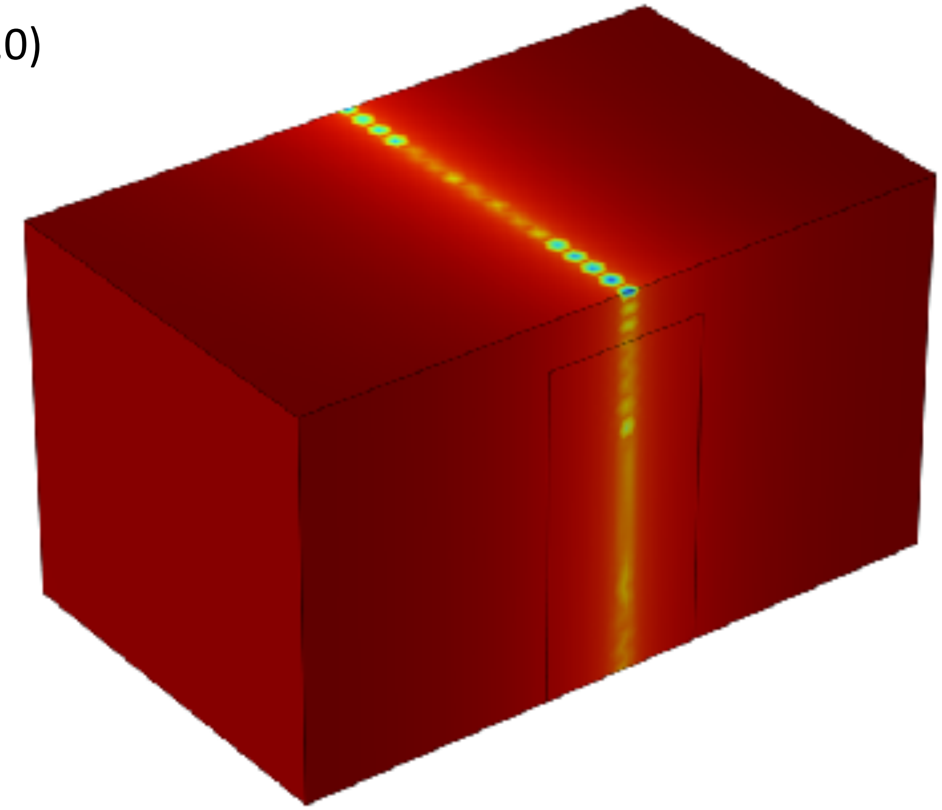
1. on the back wall (9 points)
   - 4 in the corner (1,3,9,7)
   - 1 in the middle (5)
   - 4 at the midpoints of the sides (2, 4, 6, 8)

2. at the middle of the room to distinguish the modal responses
   - 10
   - 11 and 12 at 1/4W

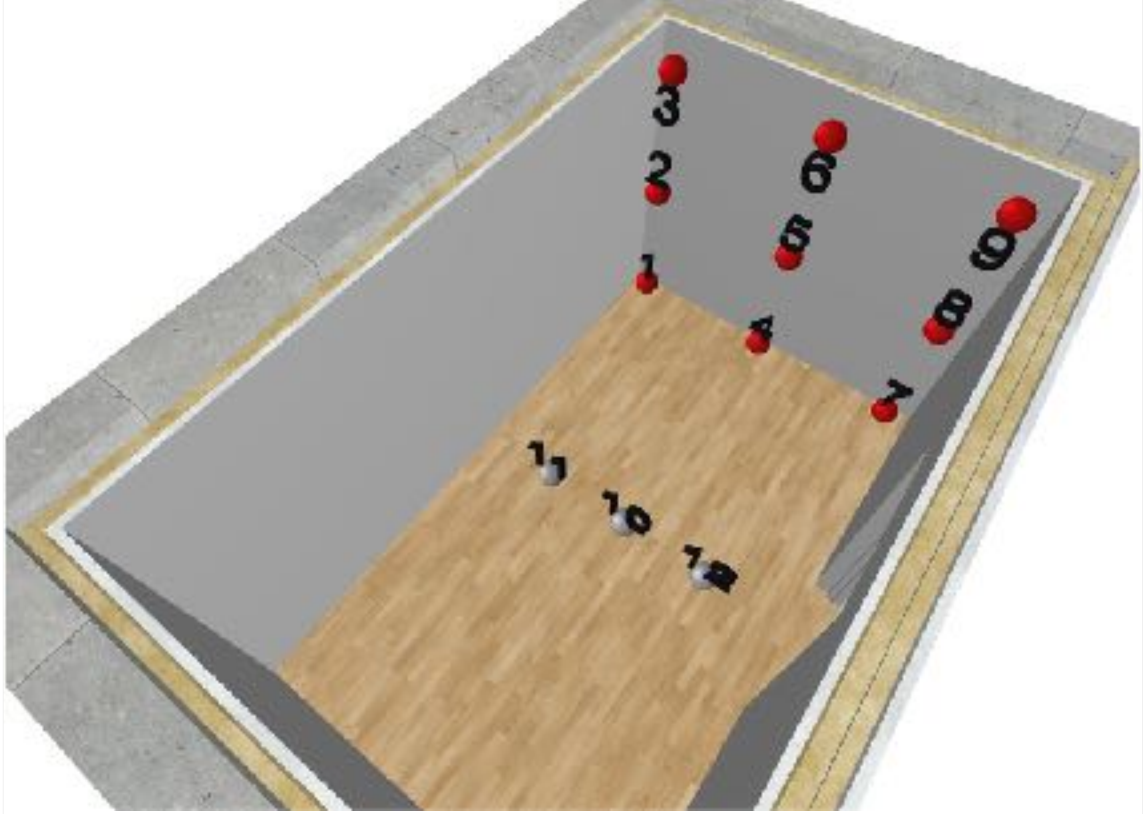
3. Points at 1/3 of the length as a control position (13, 14)

Measurements - Room modes

38
(1,0,0)

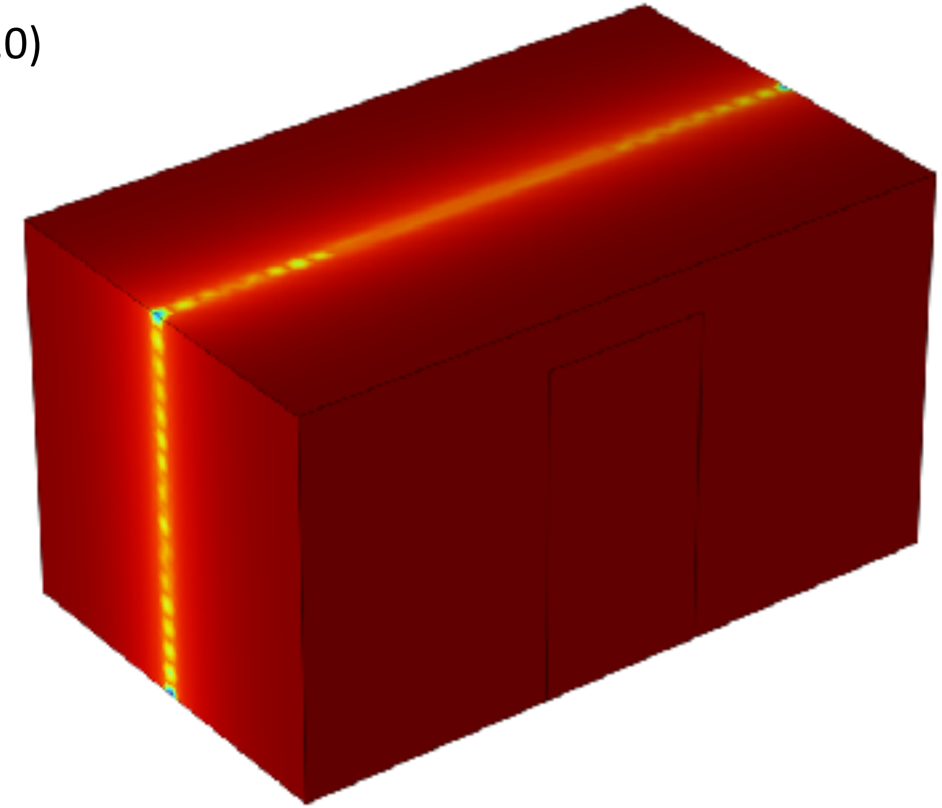


Points: 1, 2, 3, 4, 5, 6, 7, 8, 9

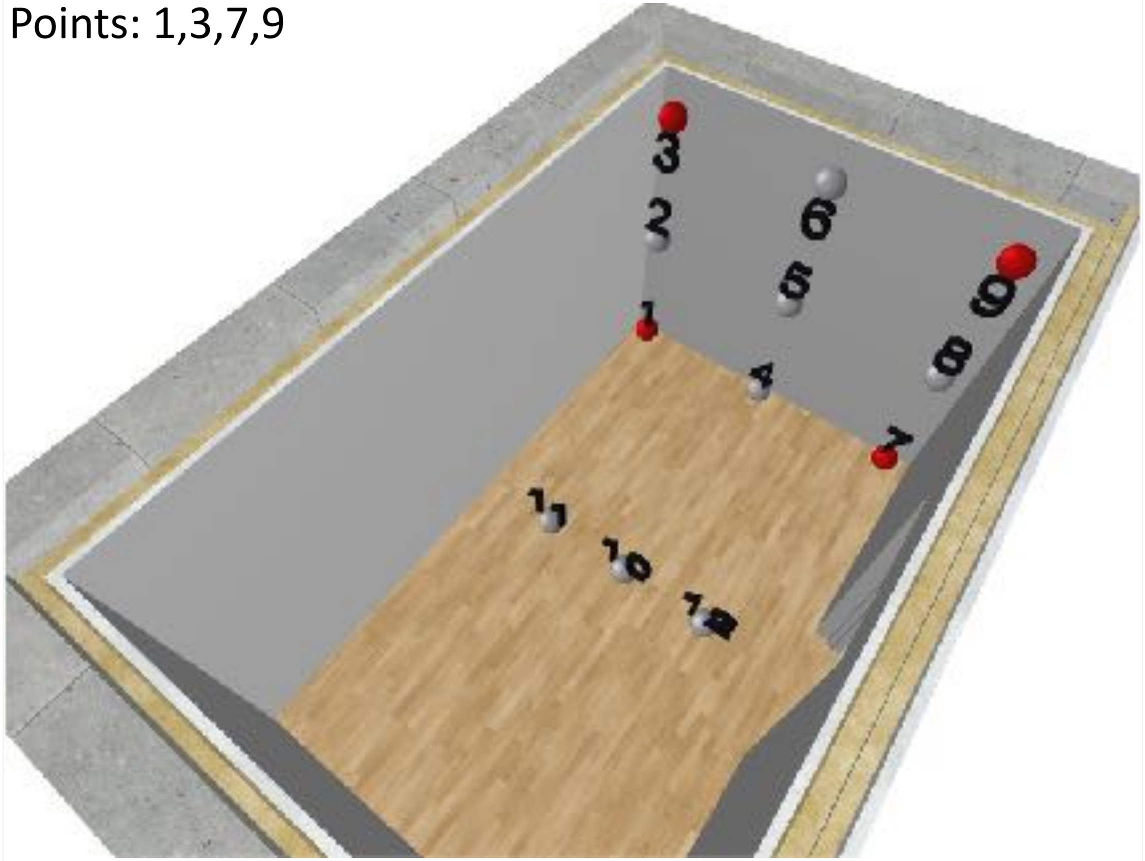


Measurements - Room modes

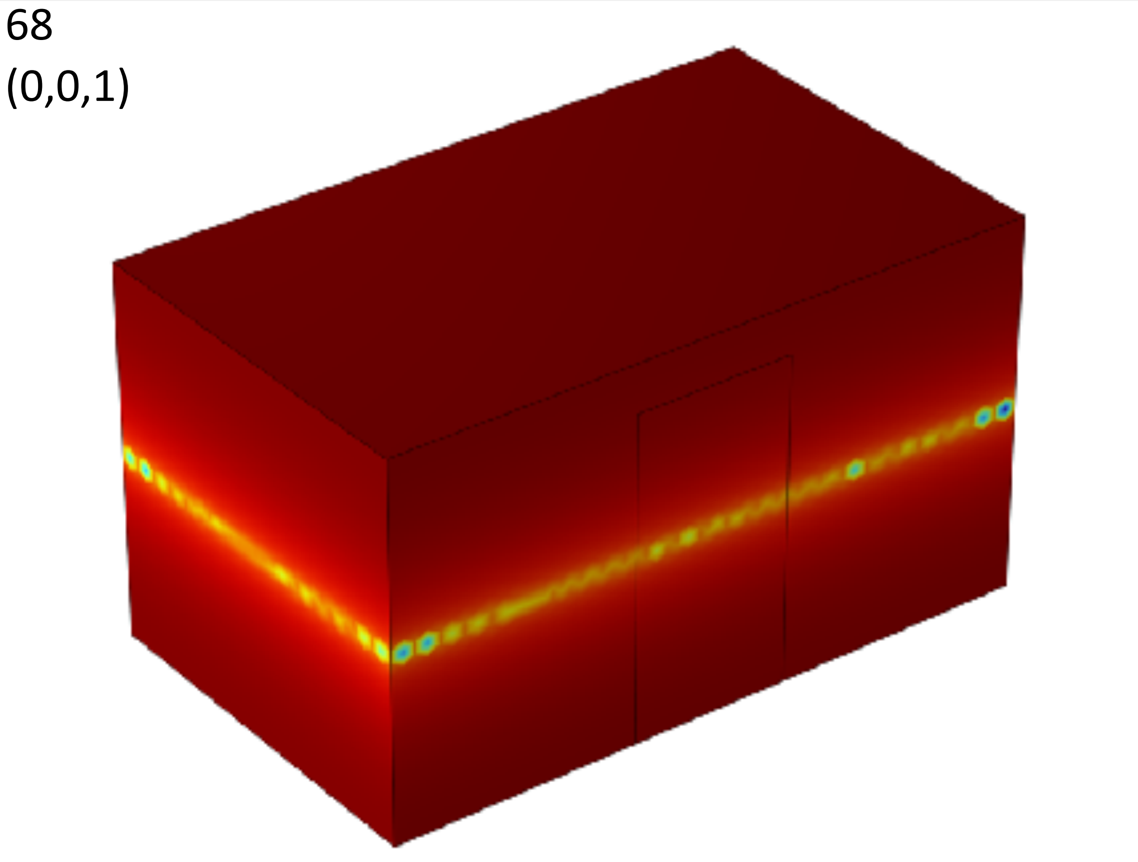
63
(0,1,0)

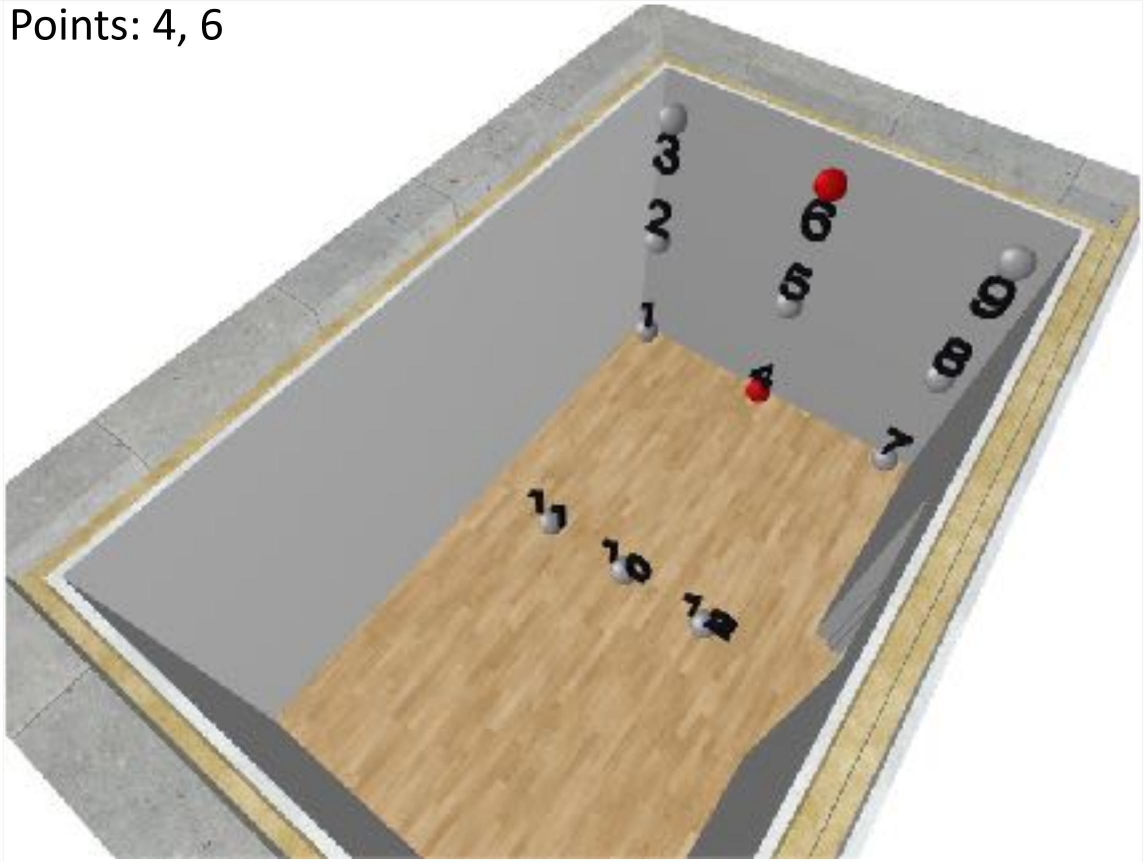


Points: 1,3,7,9



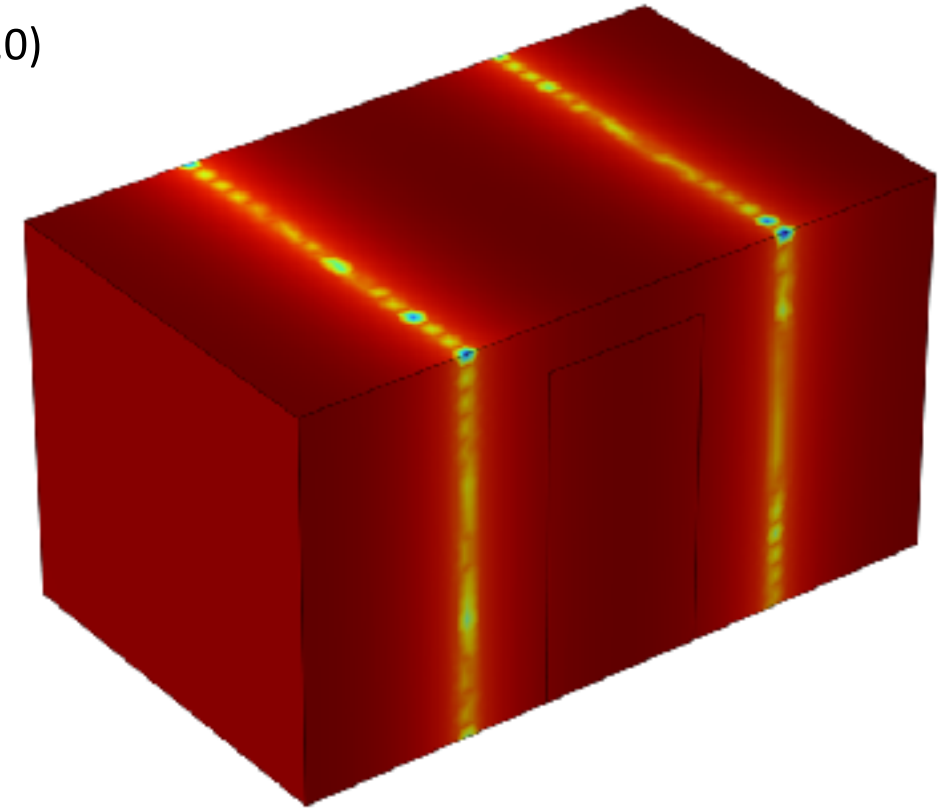
Measurements - Room modes



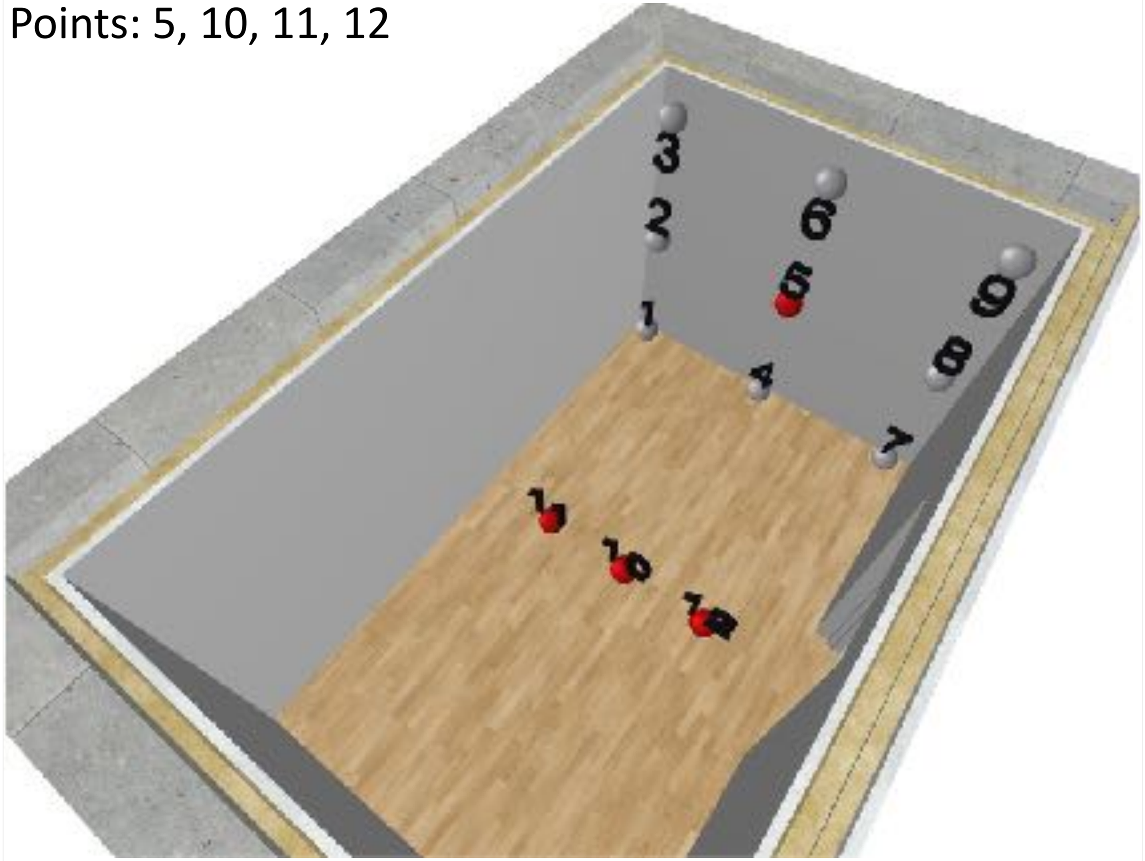


Measurements - Room modes

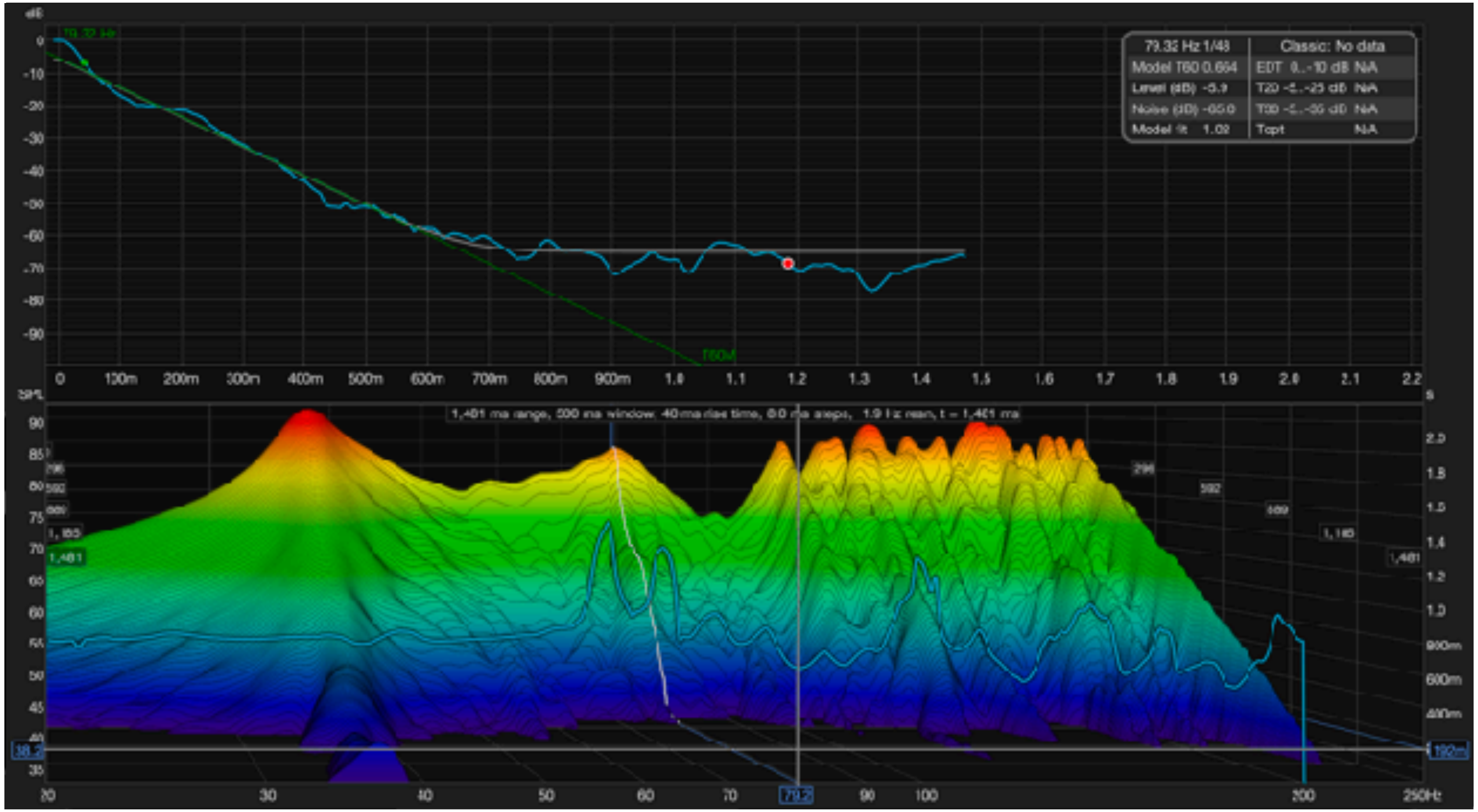
76
(2,0,0)



Points: 5, 10, 11, 12



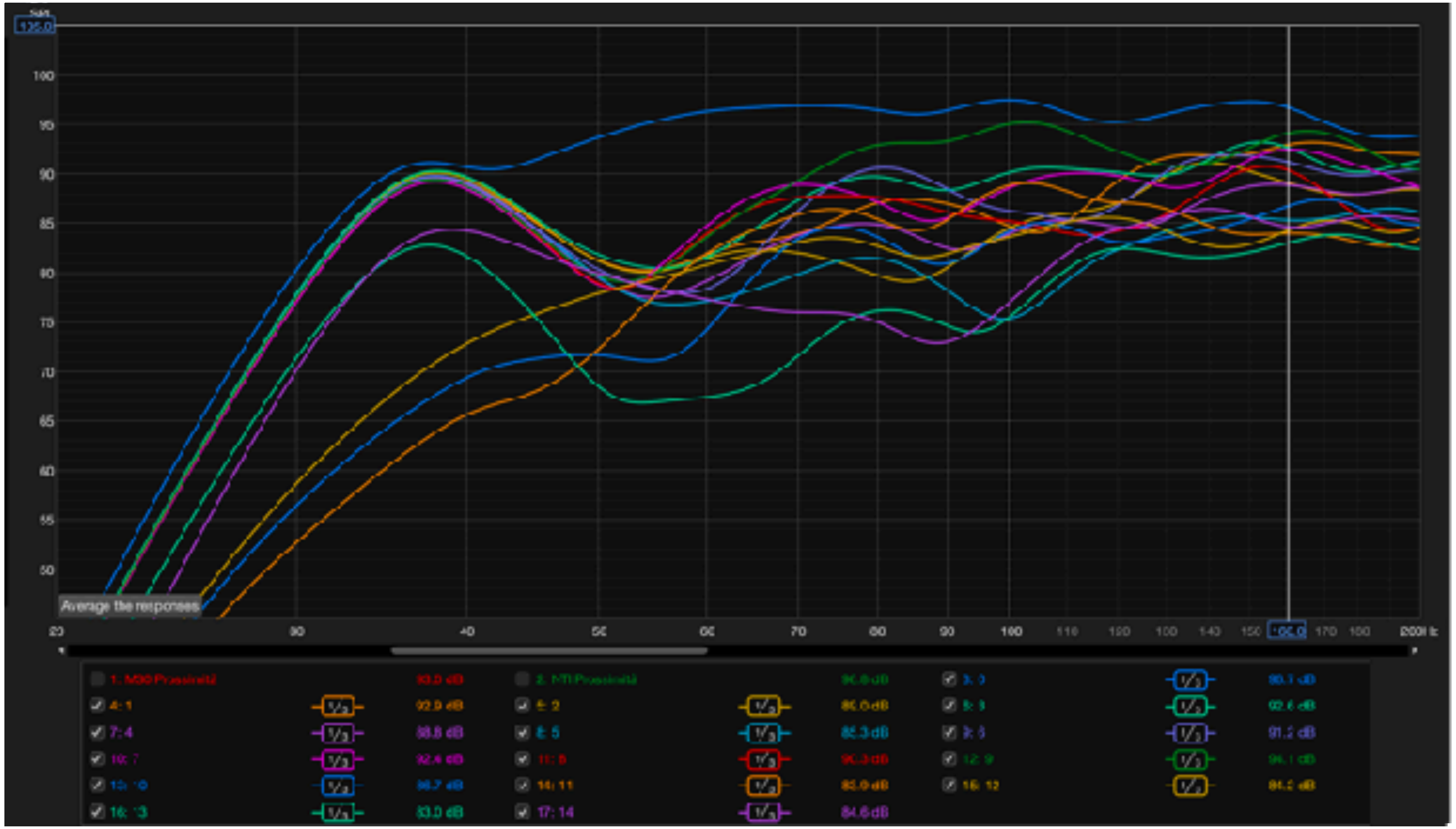
Post-processing - MT60 estimation



We estimated the MT60 for specific modes using measurements in different positions to isolate the modal decay response as much as possible.

For this analysis, we used REW's decay estimation tools.

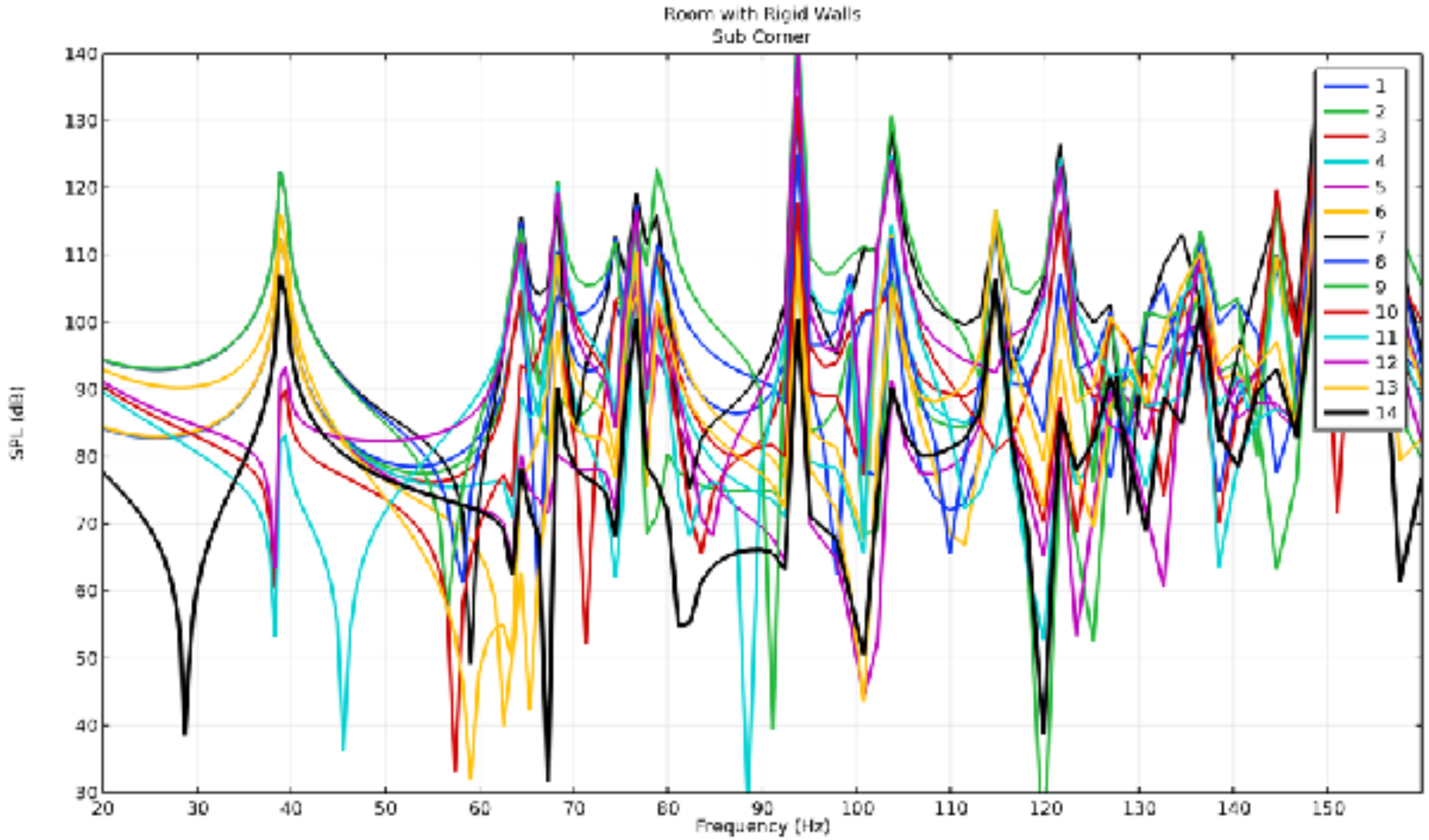
Post-processing - FR



All results shown are unsmoothed!

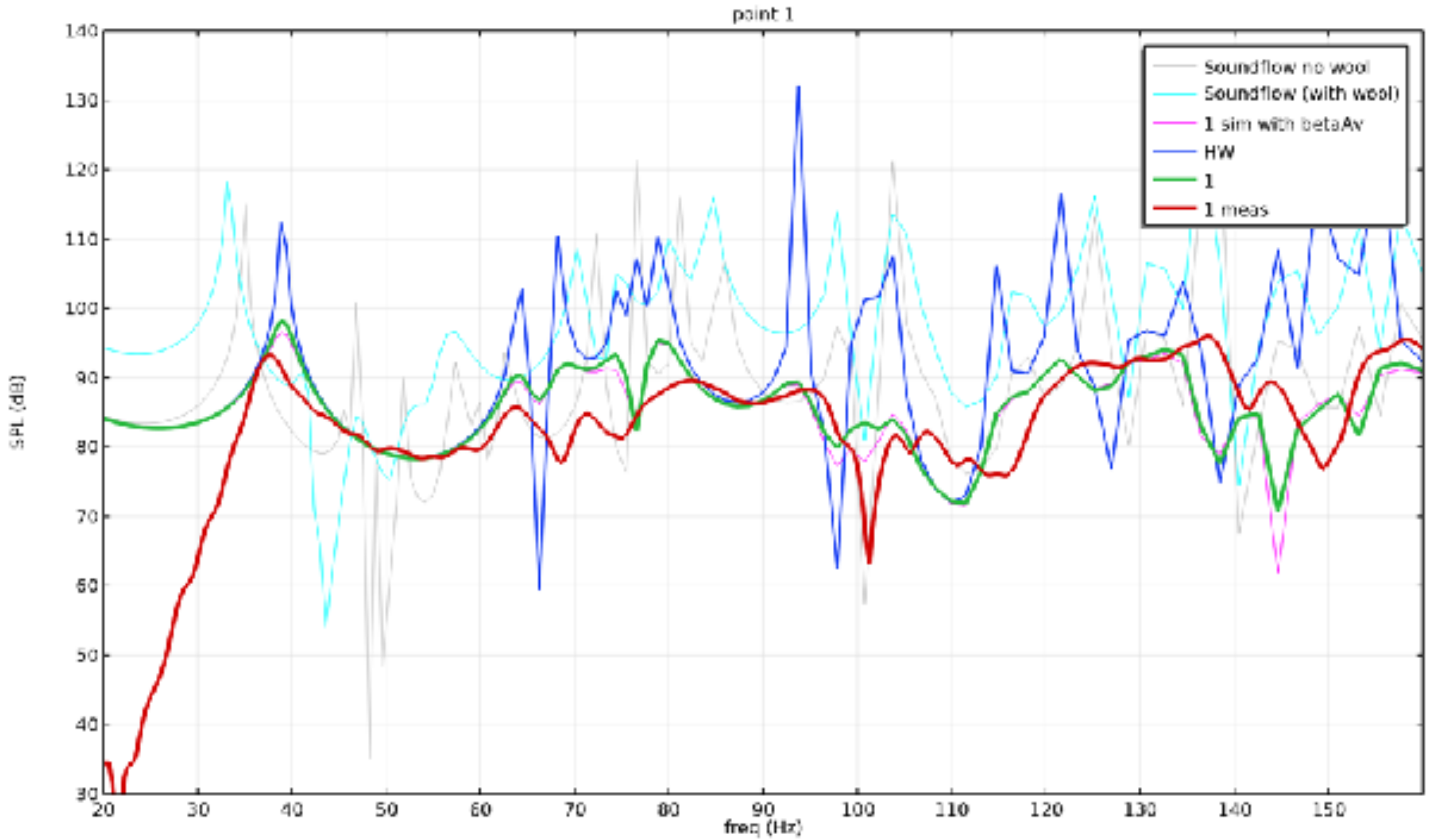
With 1/3 octave smoothing, they would appear as follows…

Modeling



We created the room model in COMSOL, included the measurement points and source location, and analyzed the room behavior (frequency response) with rigid walls

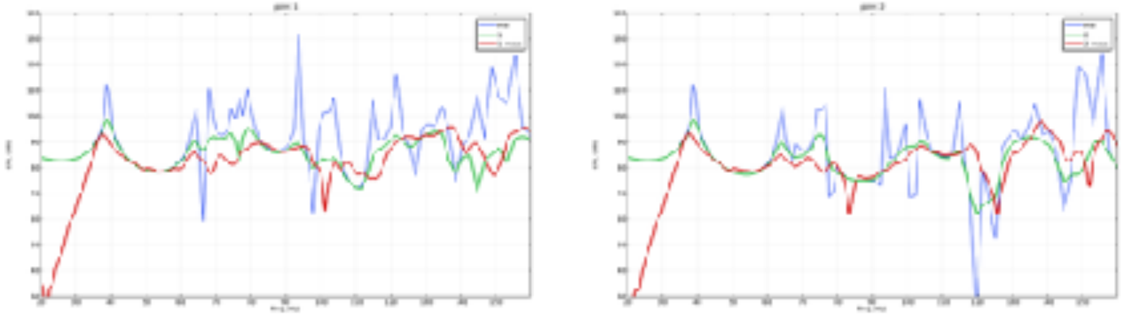
Modeling

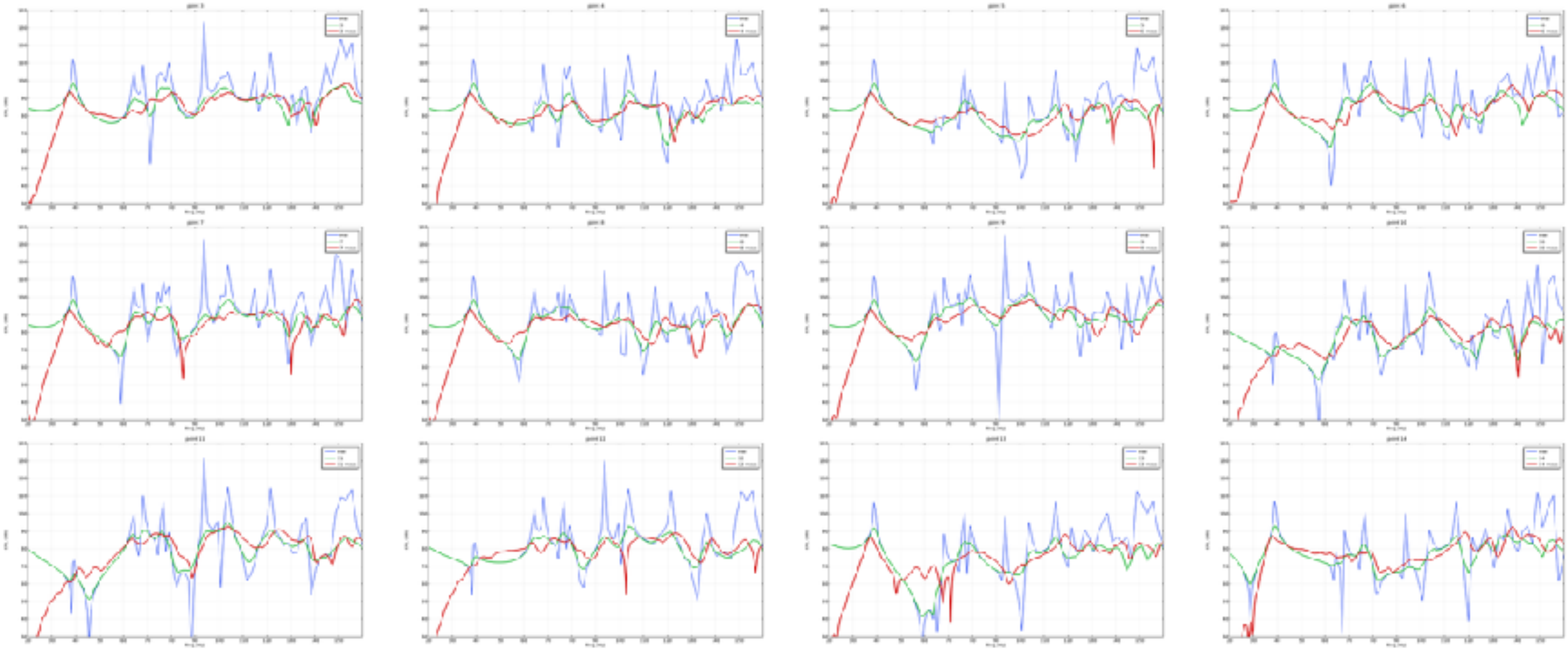


We applied the calculated acoustic impedance to the model walls and compared the frequency response results between:

- simulations using the calculated impedance
- rigid walls
- measurements

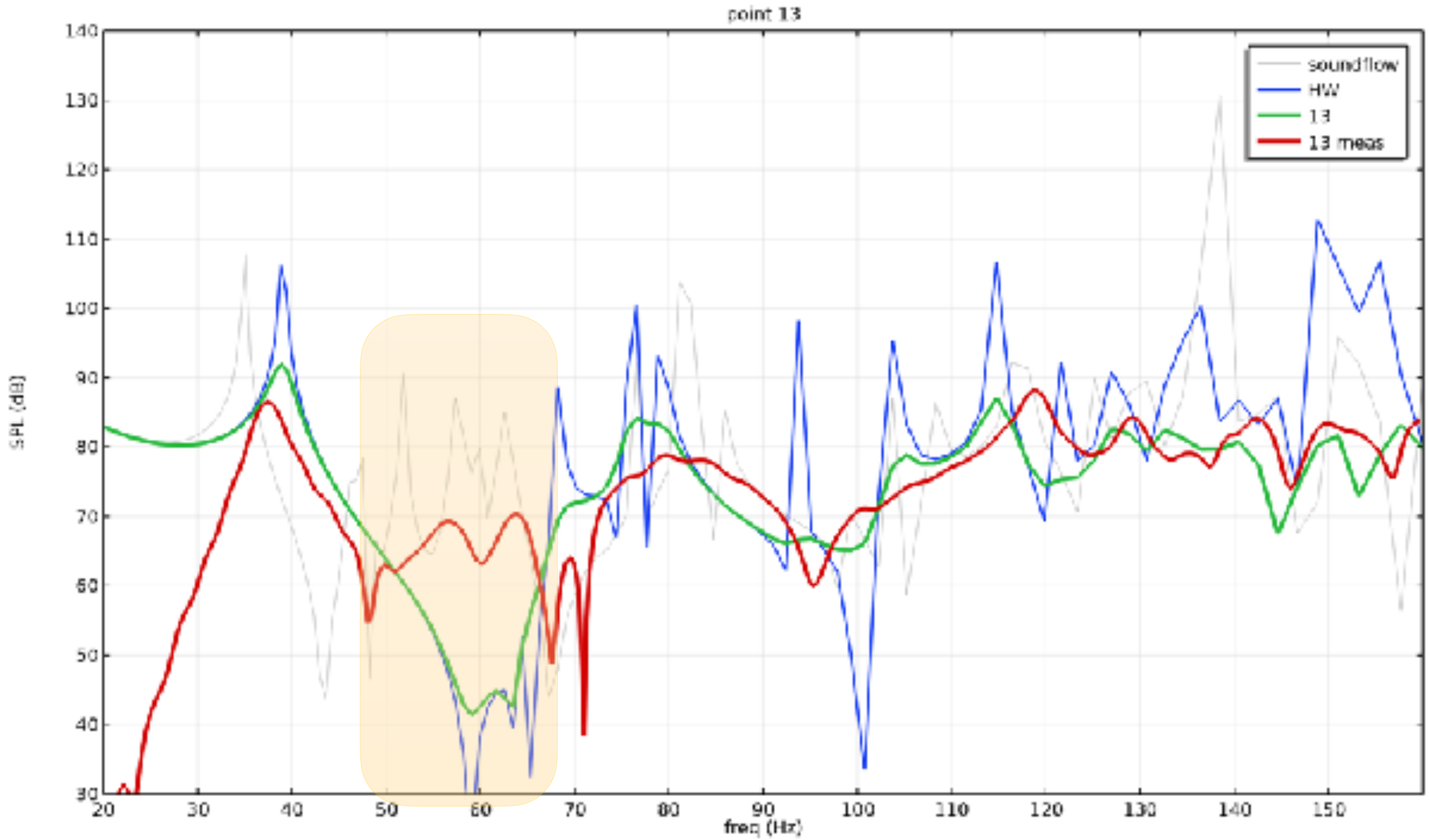
Modeling





Blue: Hard wall **Green: Simulation** **Red: Measurements**

Modeling - Soundflow tentative



The agreement between simulations and measurements is good, however this is only an estimate with an impedance value in *rayls* and doesn't have a specific frequency behavior.

The part of the spectrum most affected by drywall resonance is certainly impacted by this. For this reason, we decided to evaluate the impedances through simulation using Soundflow.

Modeling - Comments on calibration

Indeed, drywall resonances occur exactly in the range where there are major discrepancies between measurements and simulations when using a frequency-independent impedance value in *rayls*.

However, when evaluating the wall impedance response with AFMG Soundflow, the resulting frequency response shows many spikes, although the overall trend looks interesting. This needs more detailed evaluation, perhaps by introducing smoothed data or octave bands instead of third-octave bands.

If we could achieve a tuning by frequency ranges (such as by third-octave bands), this might be the key to achieving even more accurate final results

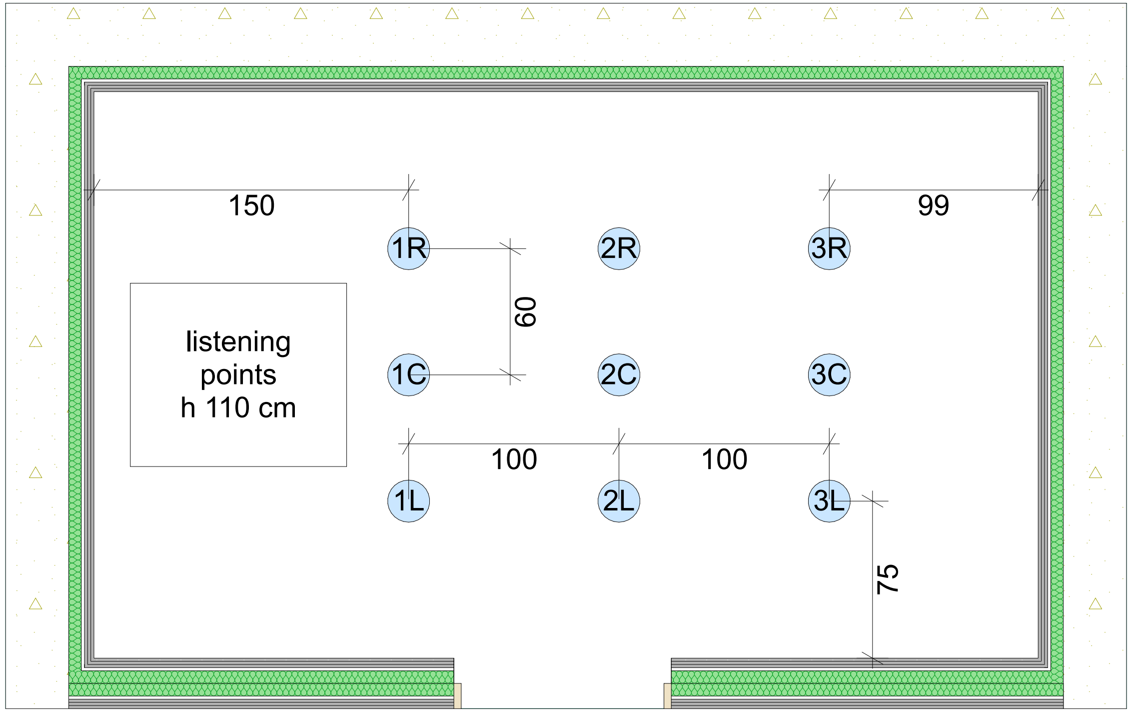
Simulations and Treatment

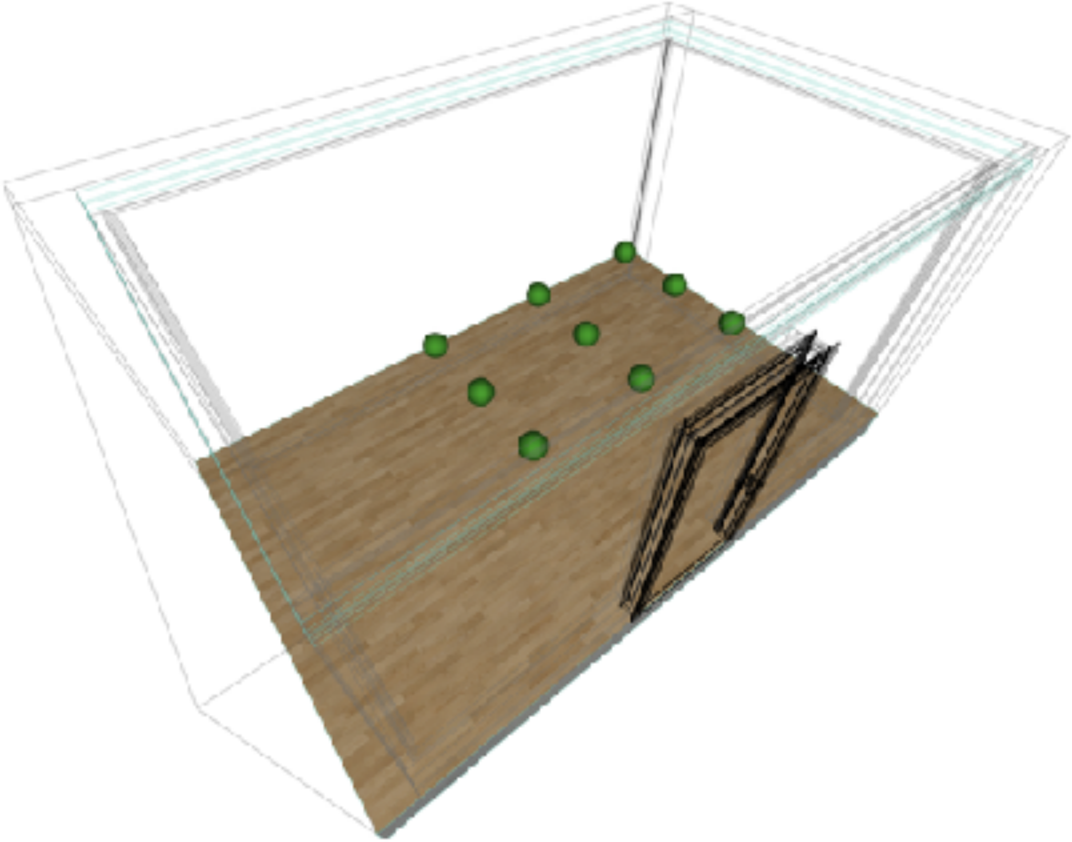
Once the model was tuned as best as possible, we were able to add more things to the room:

A. Subwoofer positions
- 1/3 W (Dolby)
- 1/2 W
- a) Cedia
- b) and b_h) Cedia
- c) Cedia
- e) Cedia
- f) Cedia
- Array with 3 Sub on front

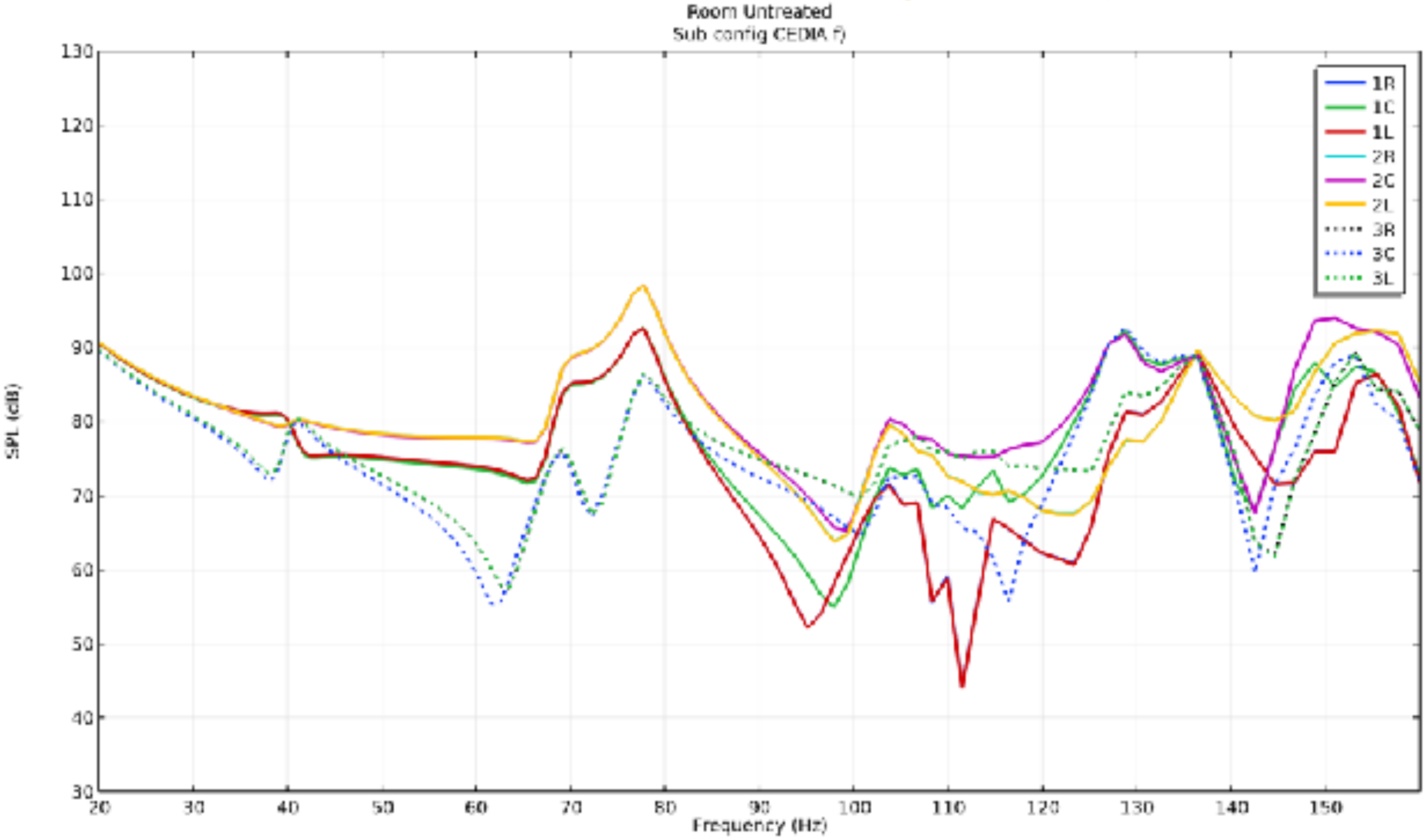
B. Acoustic Treatment
- Resonator panels 1
  (alpha constant)
- Resonator panels 2
  (alpha frequency dependent)

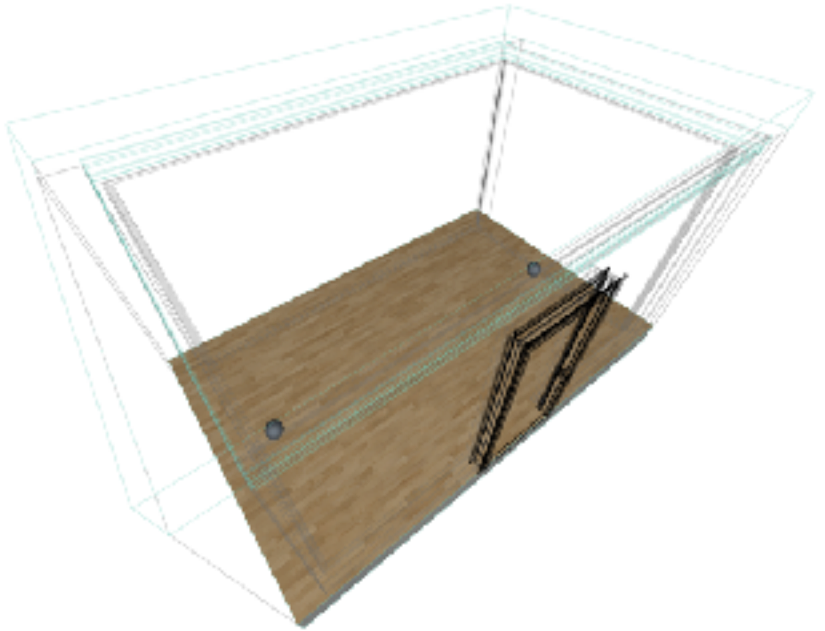
Simulations - Matrix of Positions

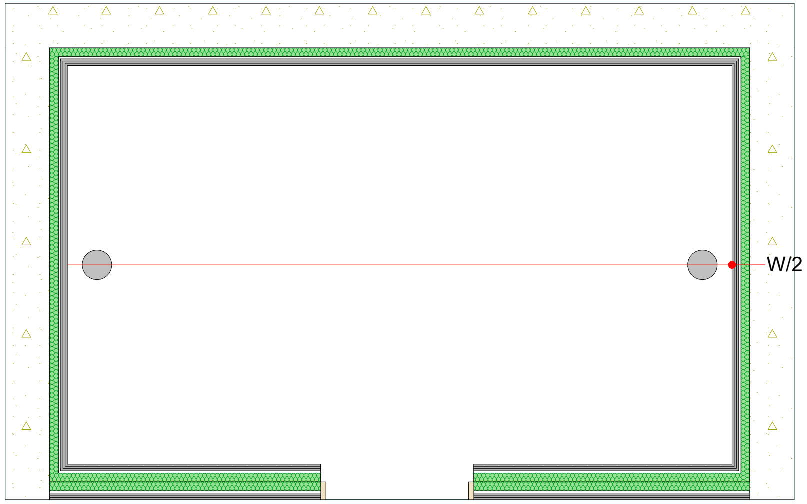




Simulations - Cedia f) Untreated







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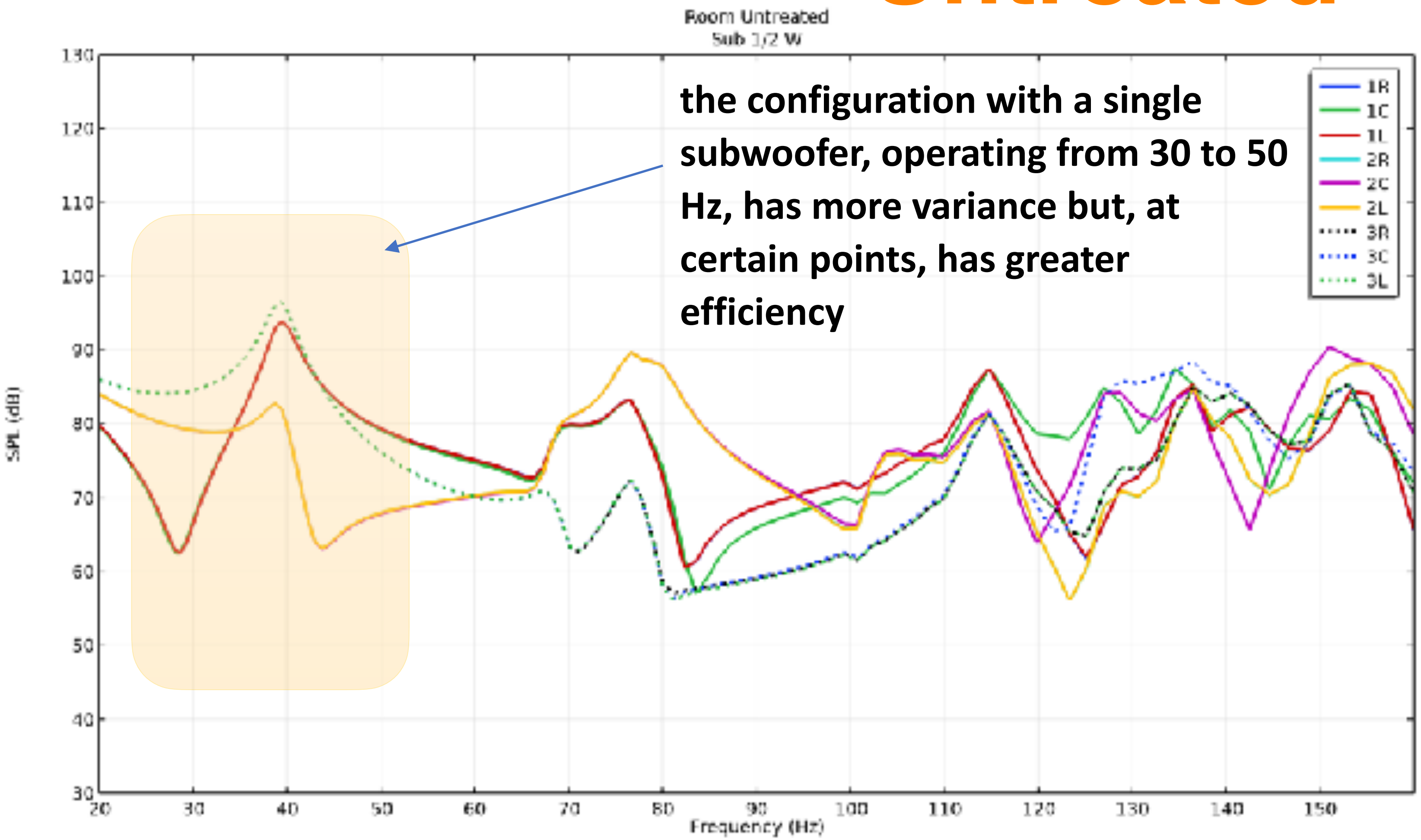
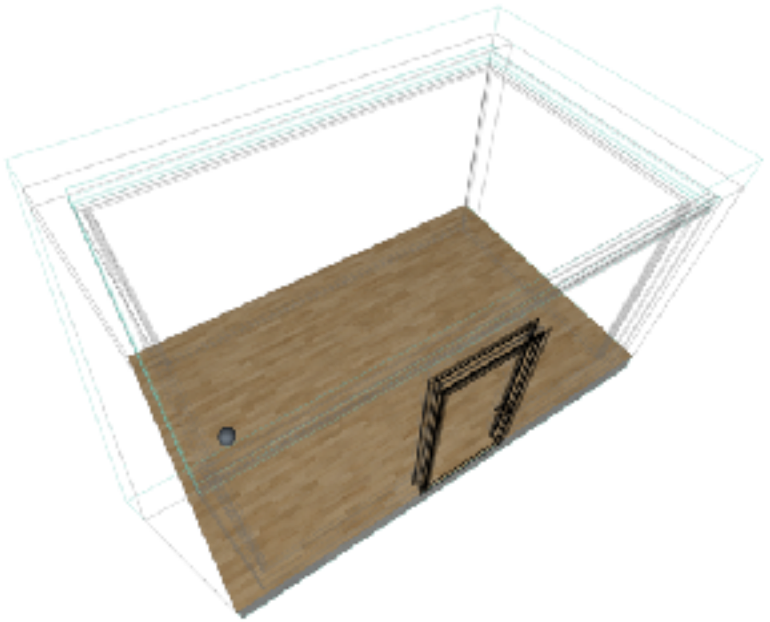
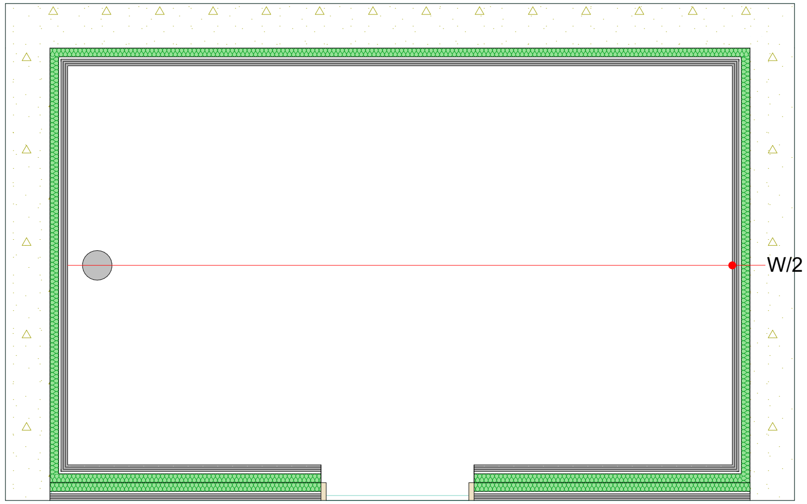
Simulations - 1/2

Untreated



the configuration with a single subwoofer, operating from 30 to 50 Hz, has more variance but, at certain points, has greater efficiency





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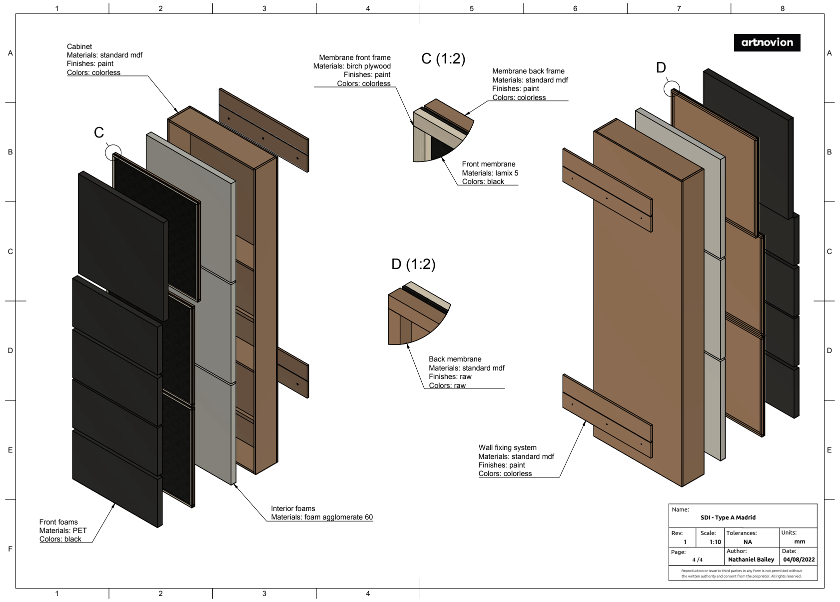
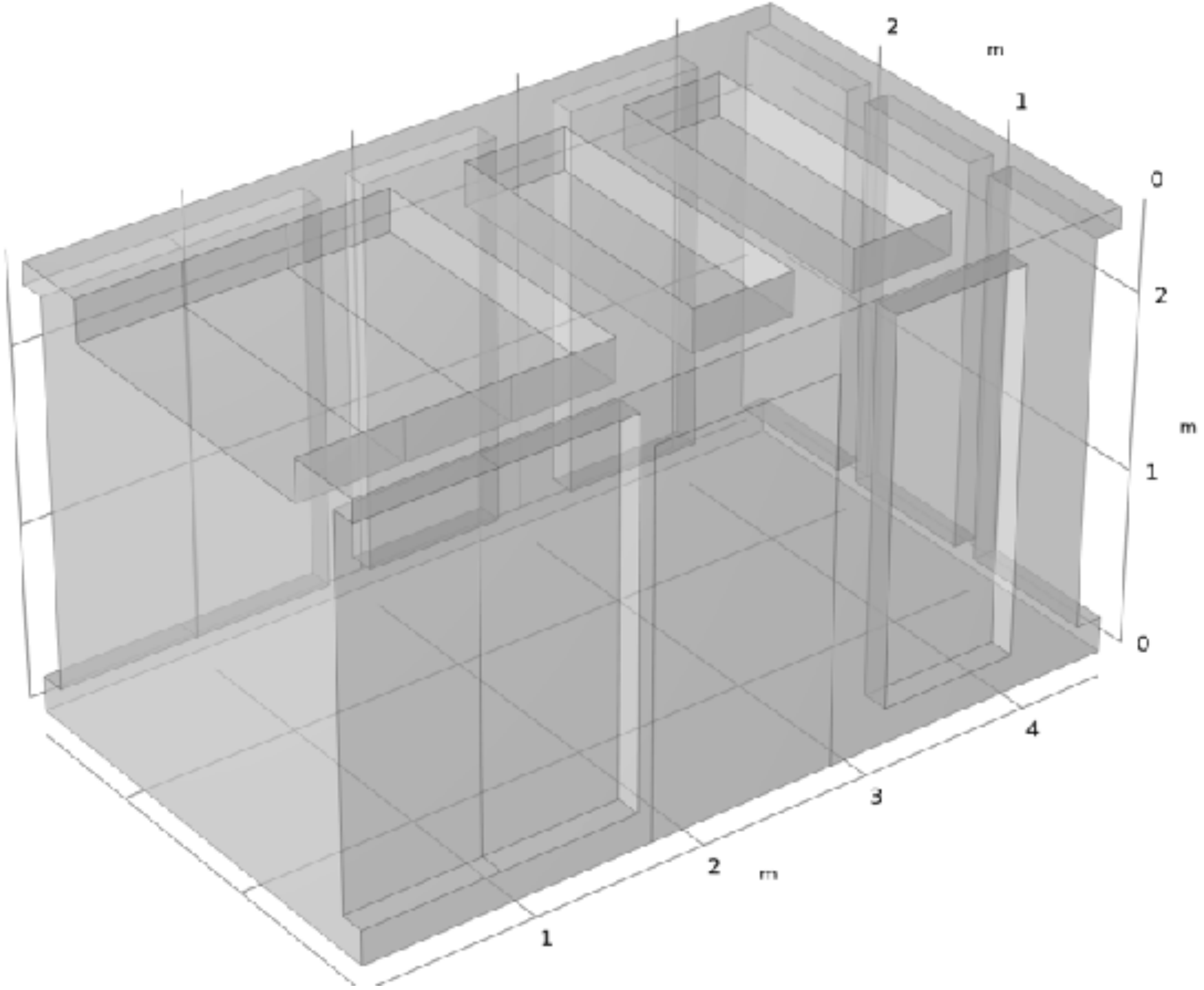
Treatment 1

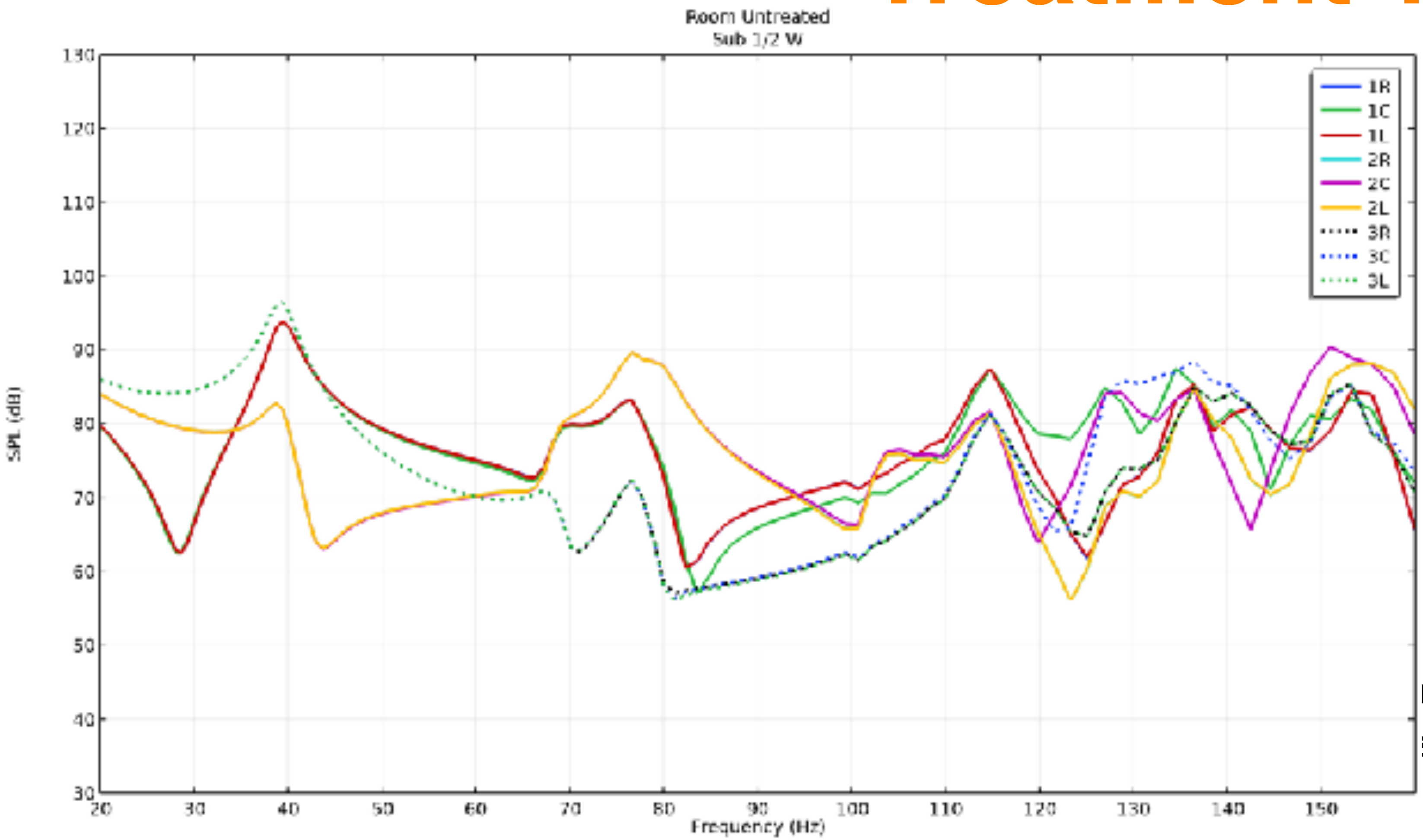


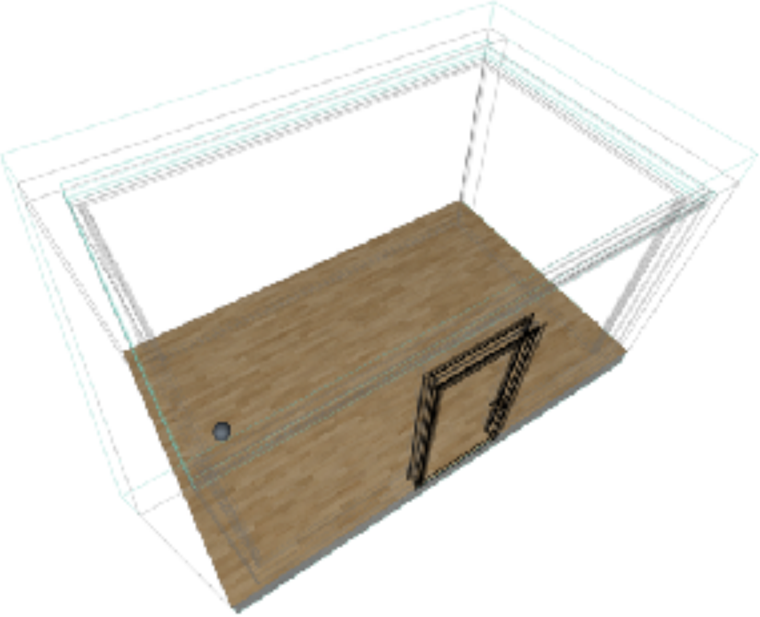


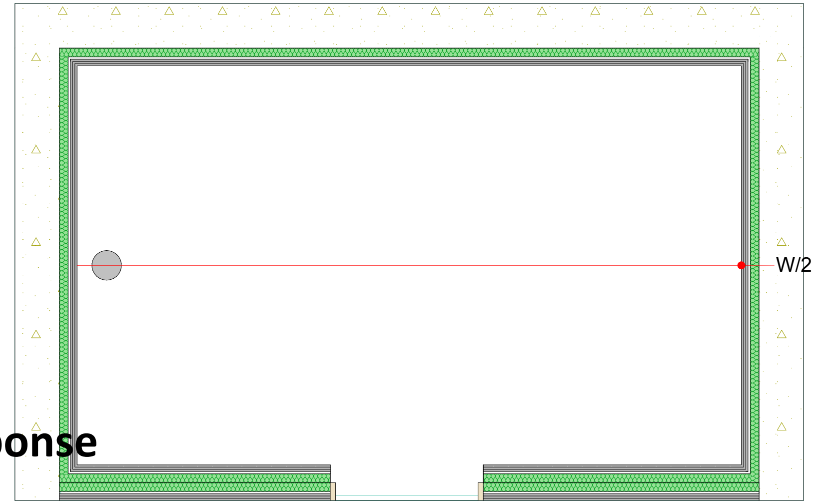
approximated constant impedance and absorption coefficient

Simulations - 1/2

Treatment 1







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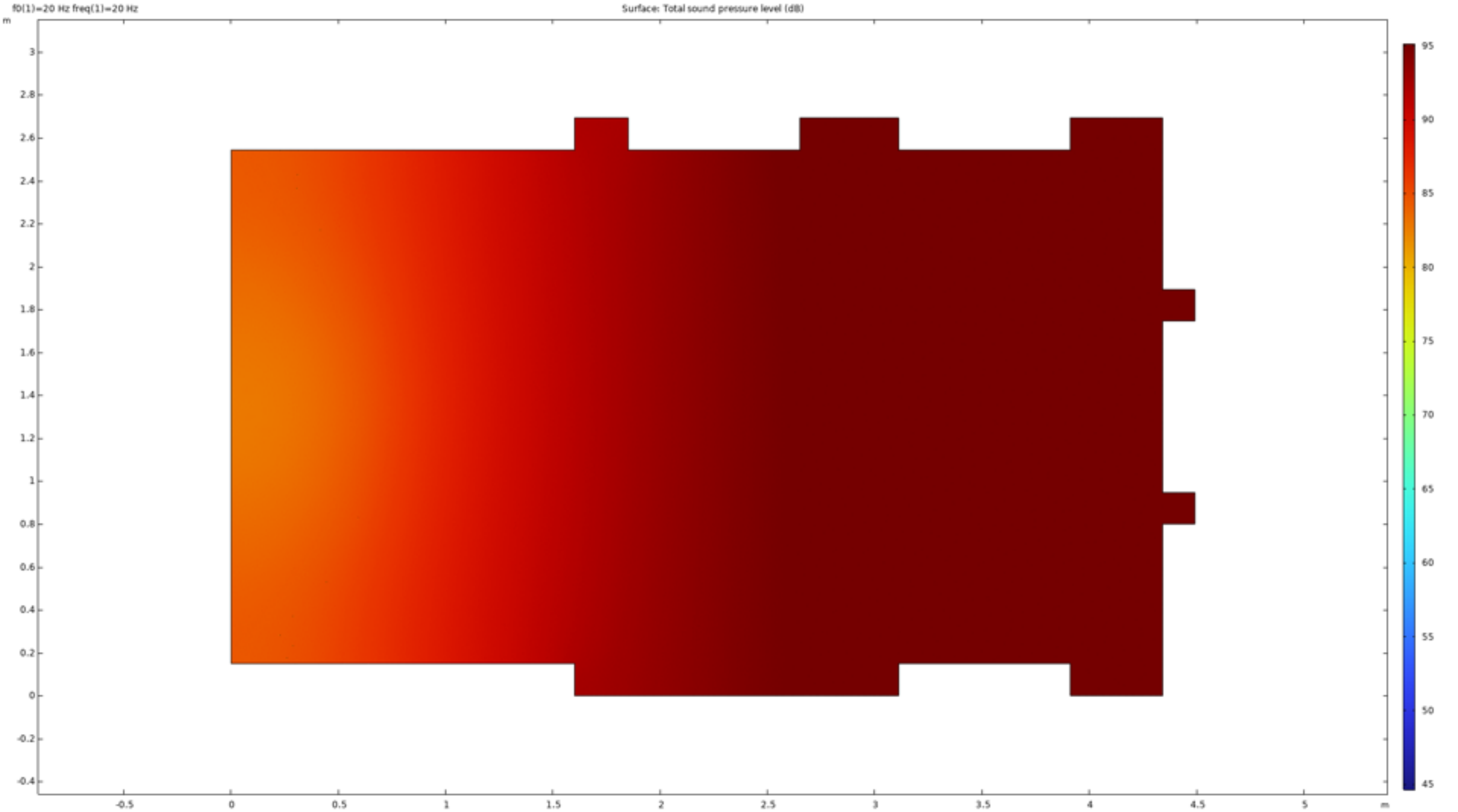
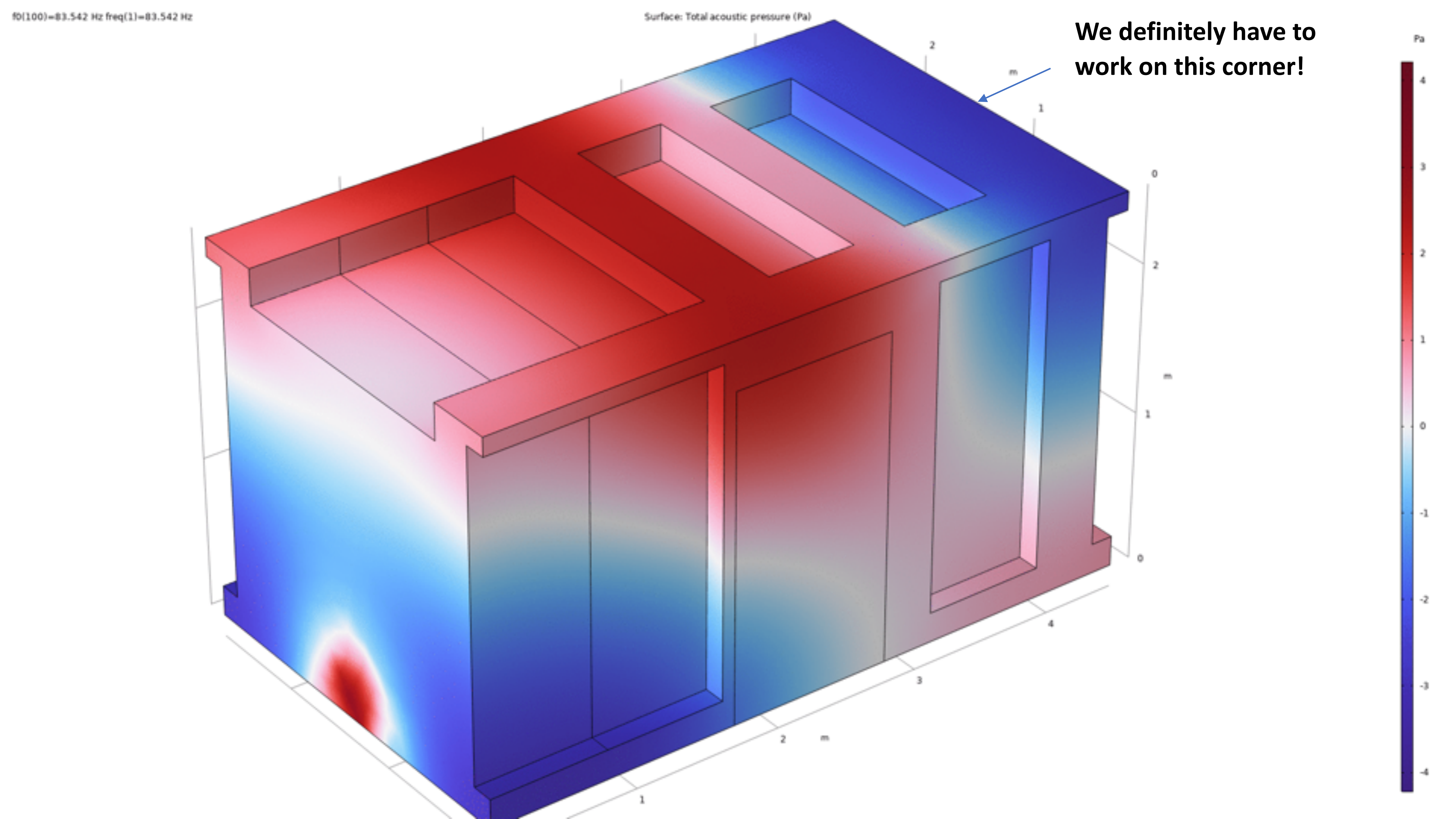
STUDIO SOUND SERVICE

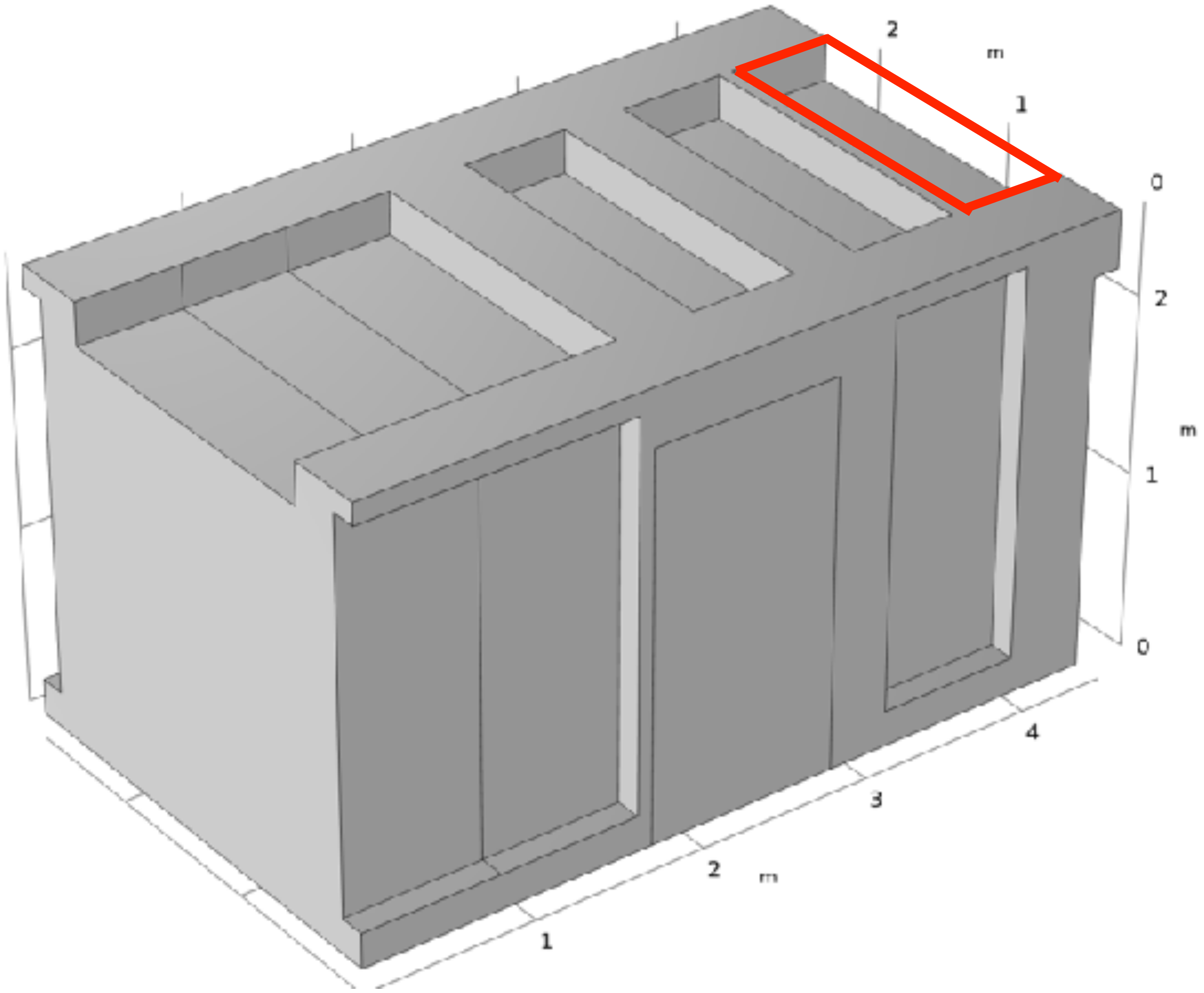


f0(1)=20 Hz freq(1)=20 Hz
Surface: Total sound pressure level (dB)
m
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
m
95
90
85
80
75
70
65
60
55
50
45


f0(100)=83.542 Hz freq(1)=83.542 Hz
Surface: Total acoustic pressure (Pa)
We definitely have to work on this corner!
Pa

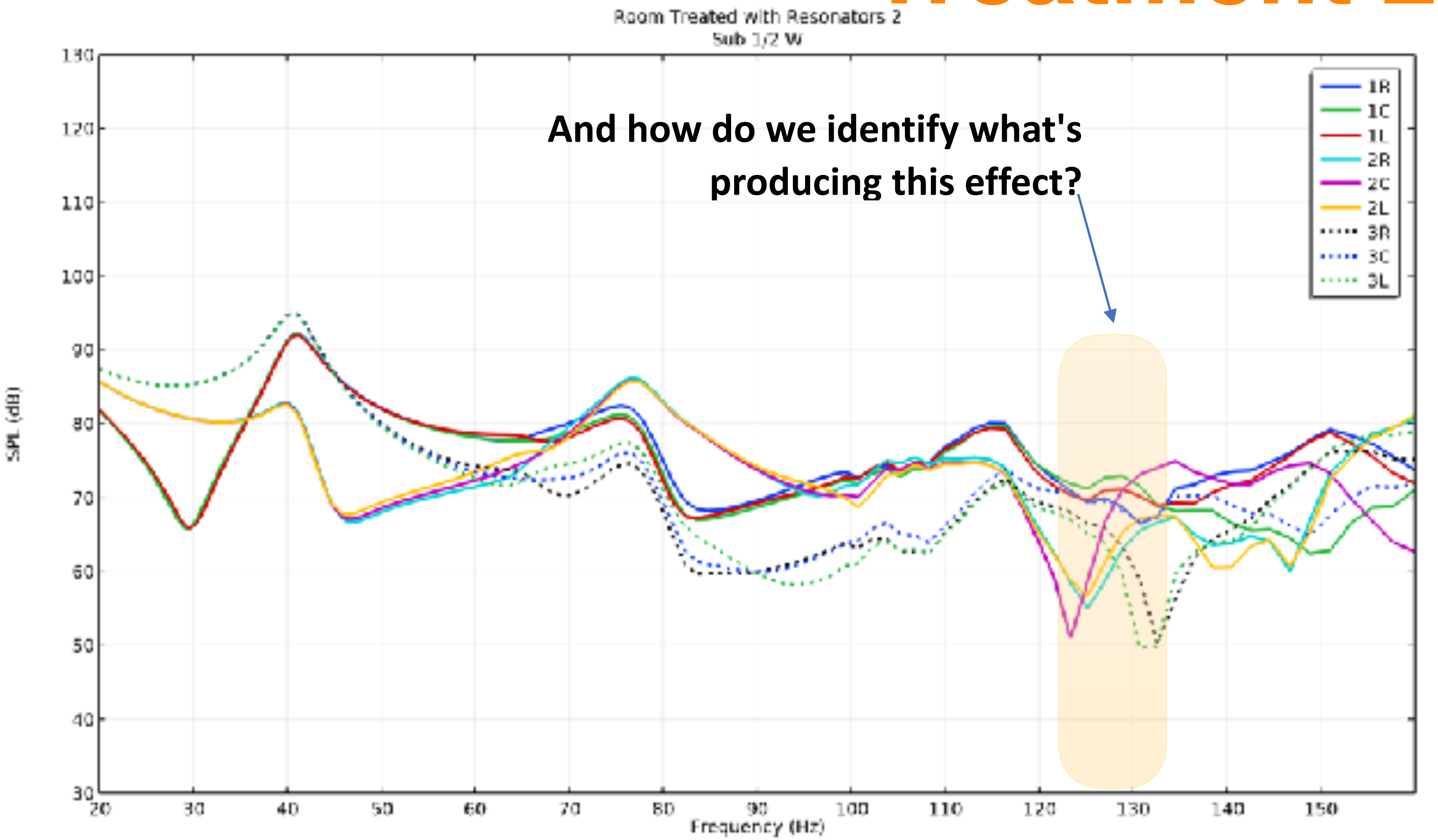
Treatment 2

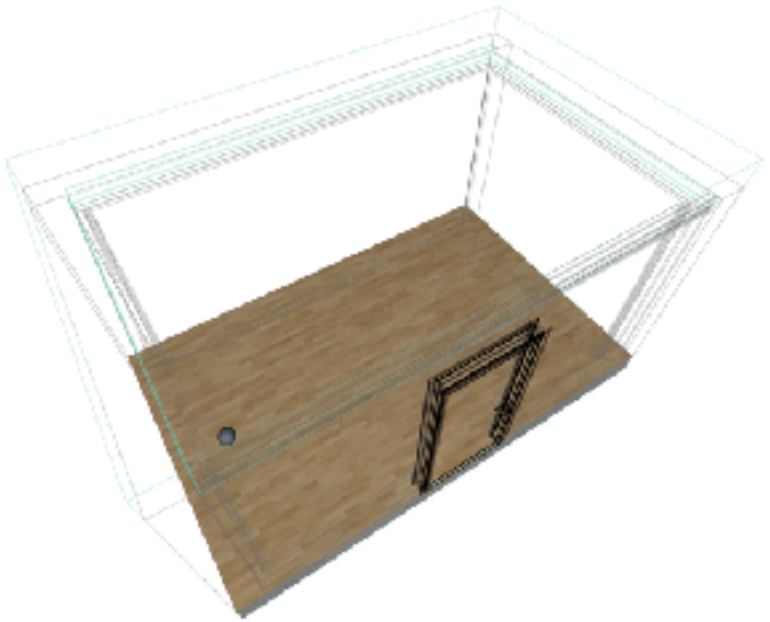
- added a new resonator to the rear ceiling section
- the absorption coefficient and impedance have been better analyzed across frequencies

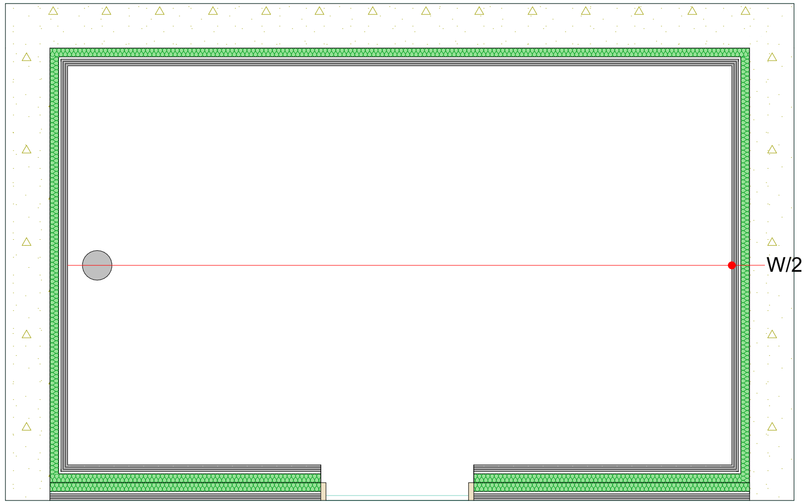


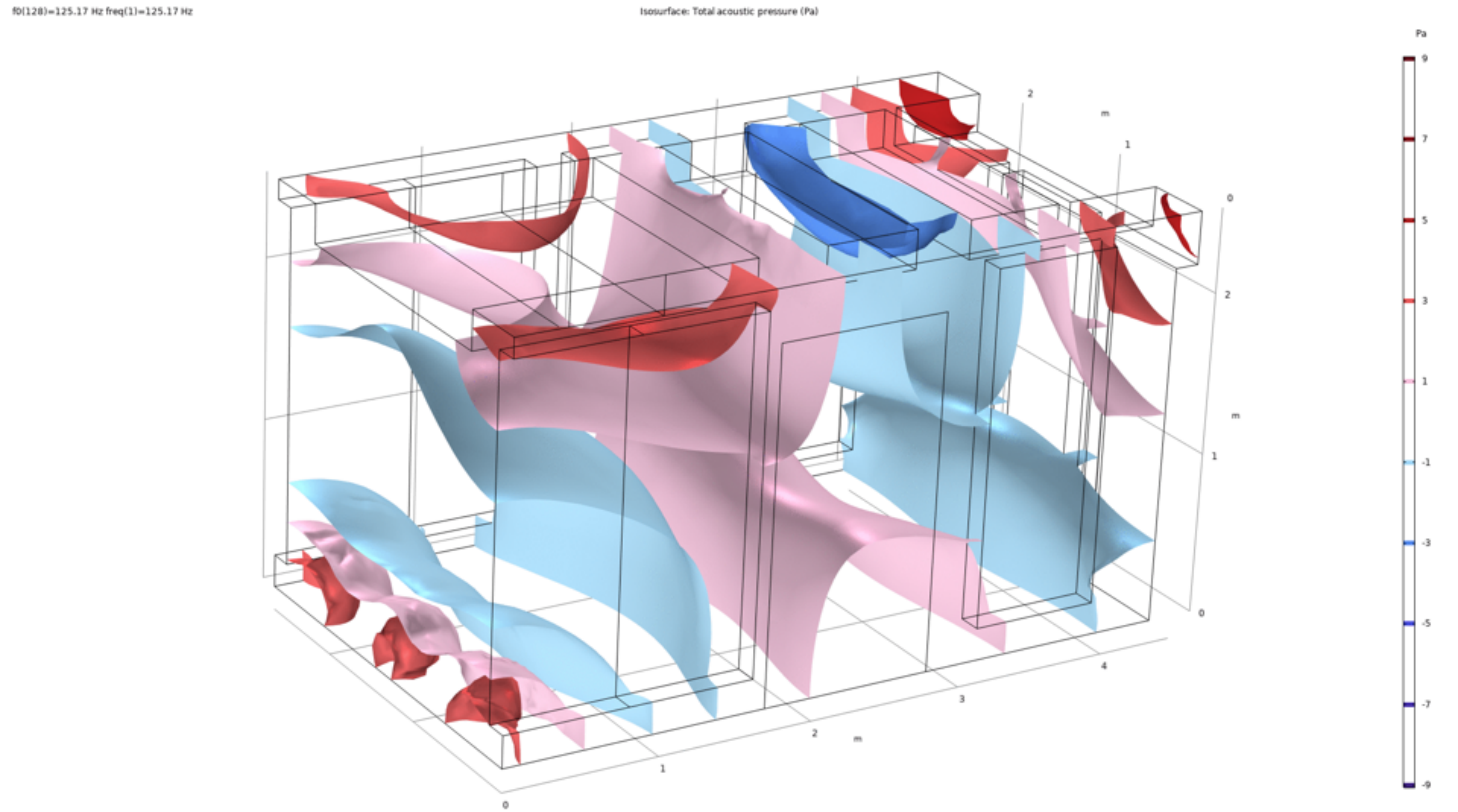
Simulations - 1/2

Treatment 2

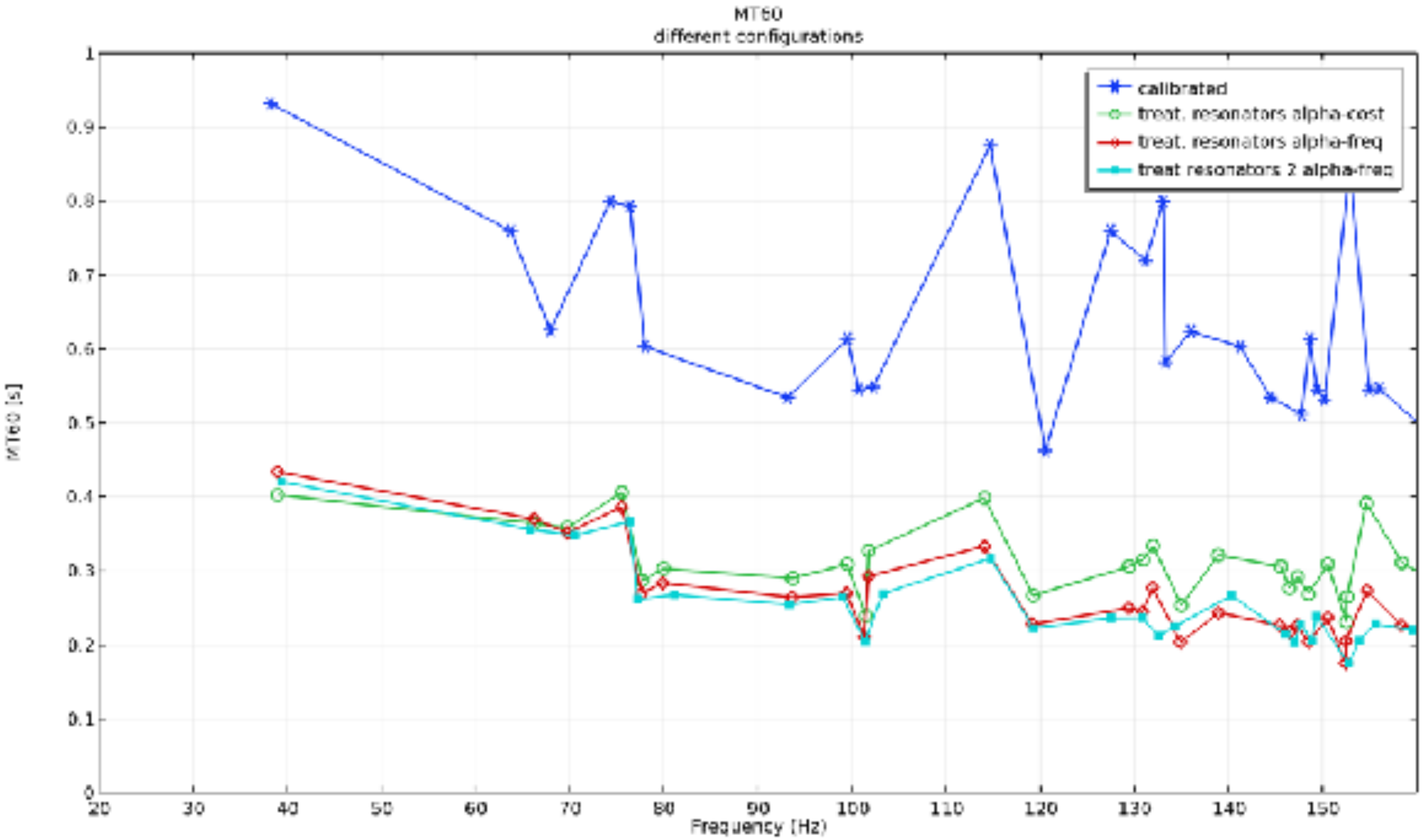







f0(128)=125.17 Hz freq(1)=125.17 Hz
Isosurface: Total acoustic pressure (Pa)
Pa
9
7
5
3
1
-1
-3
-5
-7
-9
m
0
1
2
3
4
m
0
1
2
m
0
1
2

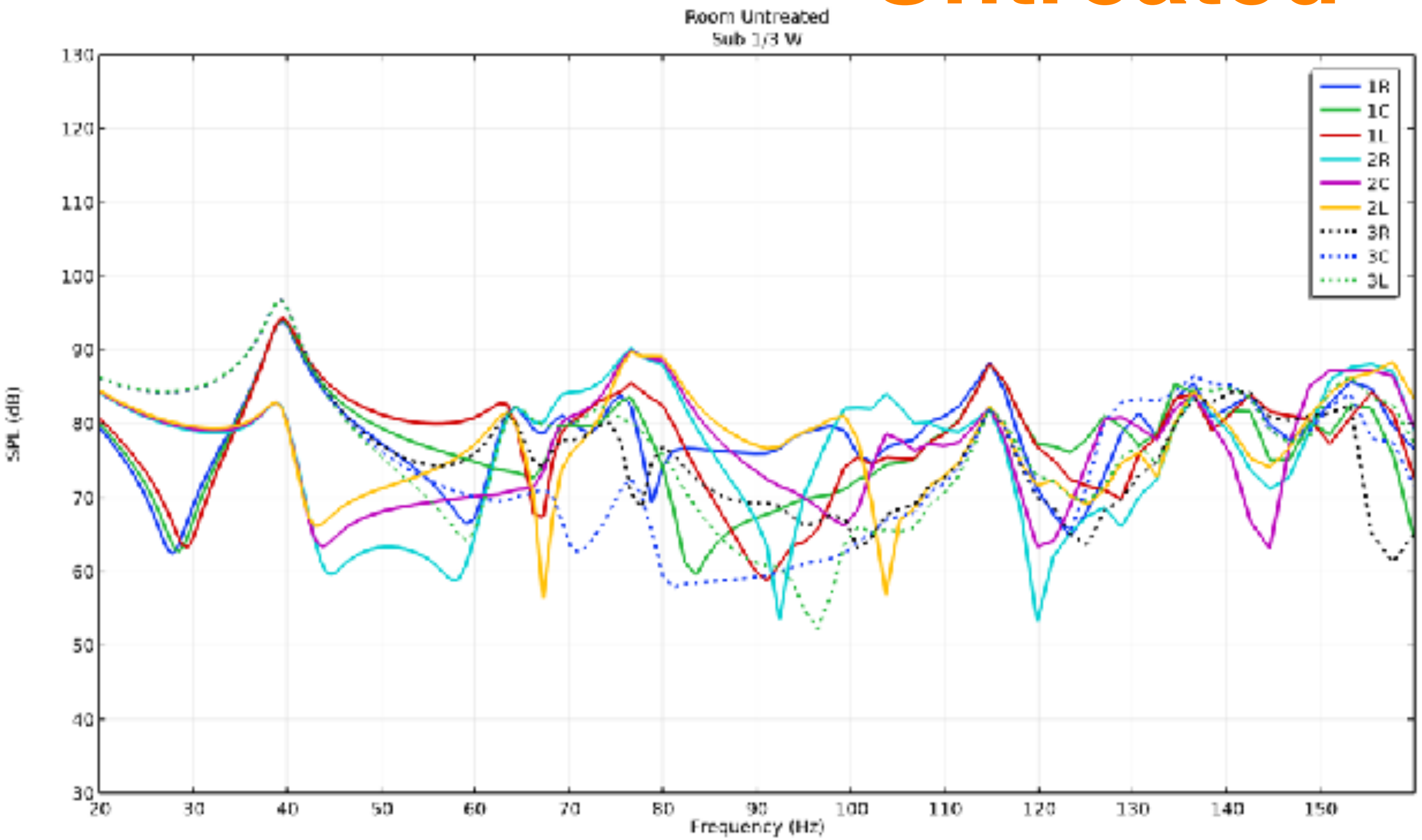
Simulations and Treatment - MT60

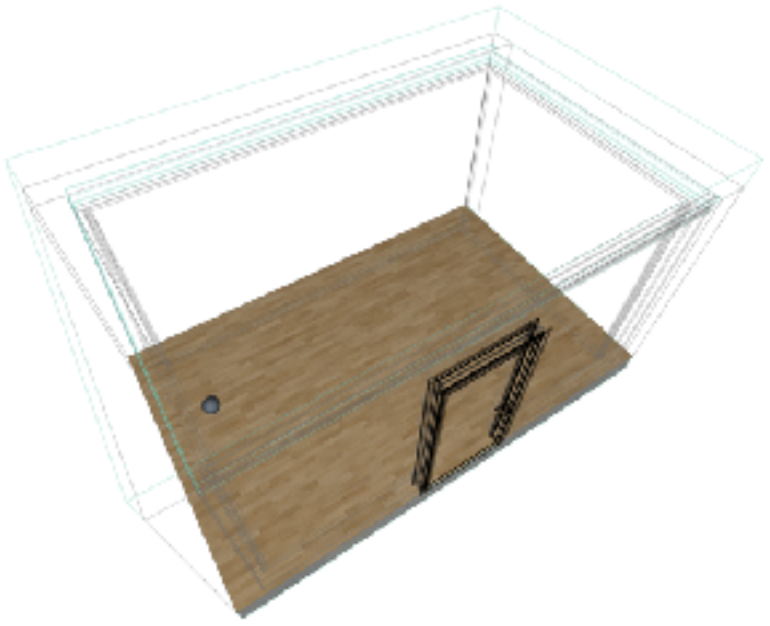


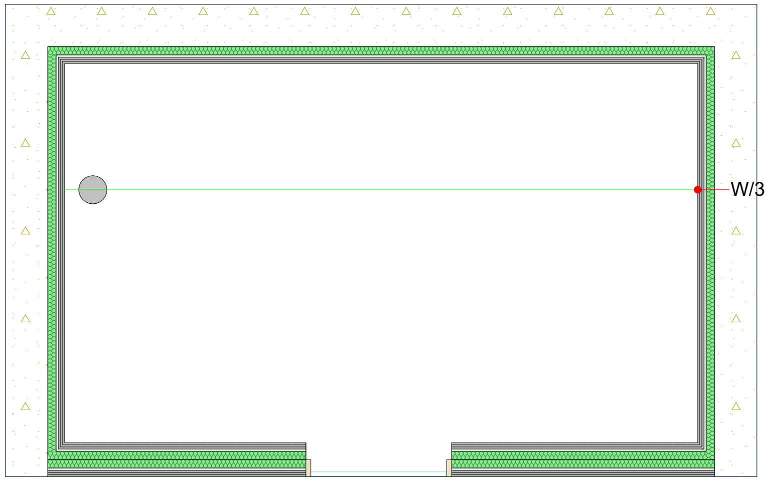
We performed a slight fine-tuning to match the resimulated MT60s with the measured ones

(actually, to simplify, we ultimately used an average β value derived from the calibration)

Simulations - Dolby 1/3
Untreated







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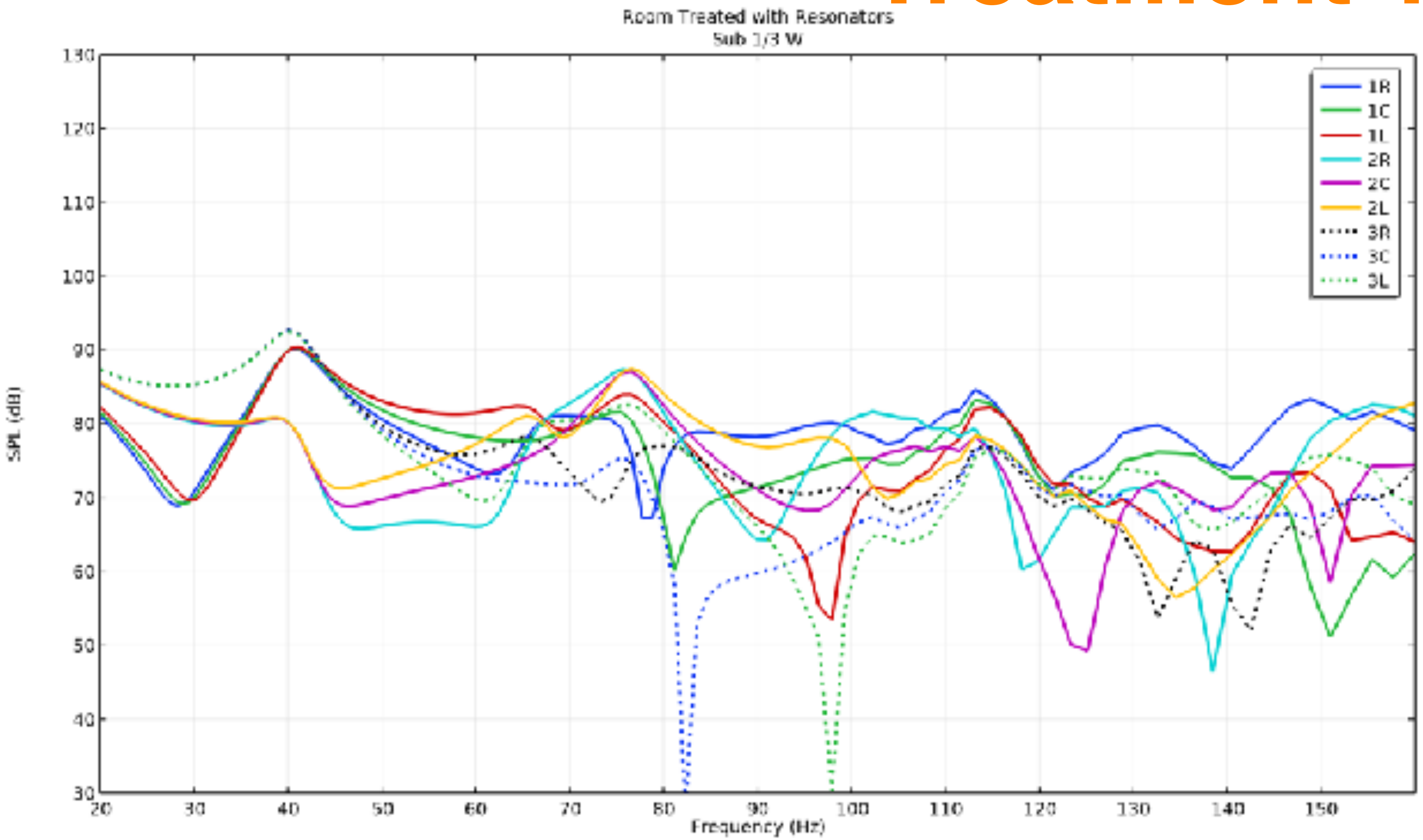
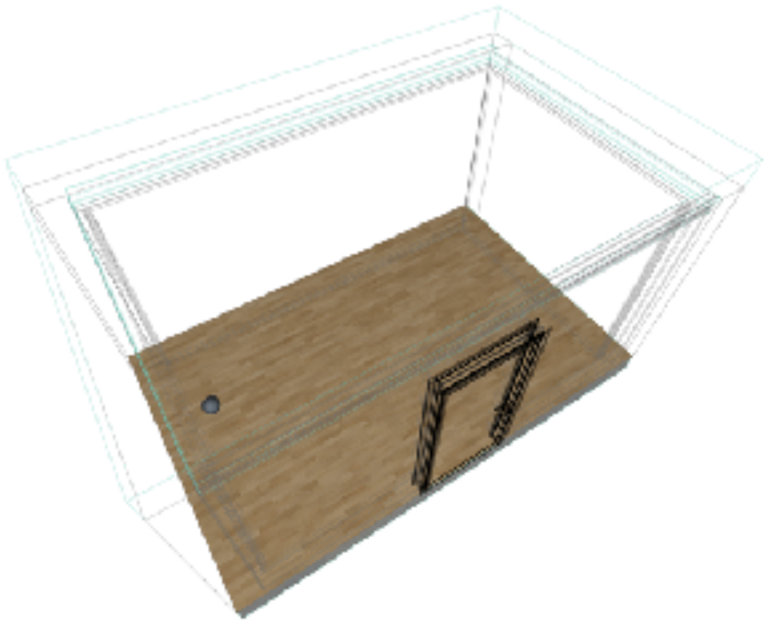
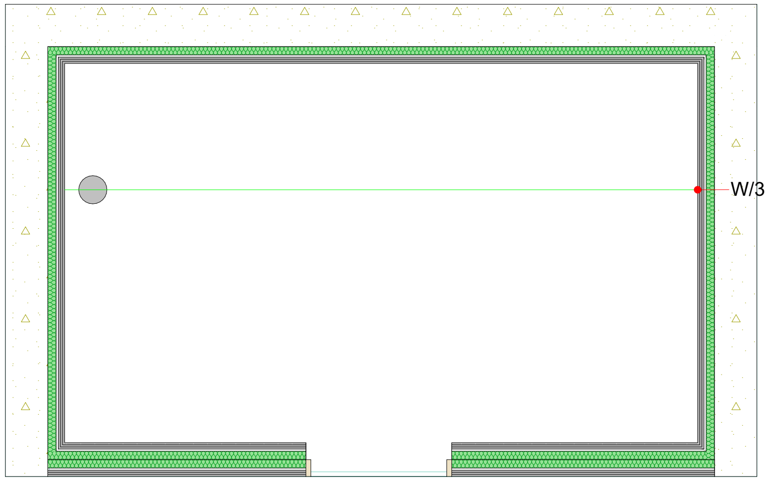
Simulations - Dolby 1/3 Treatment 1







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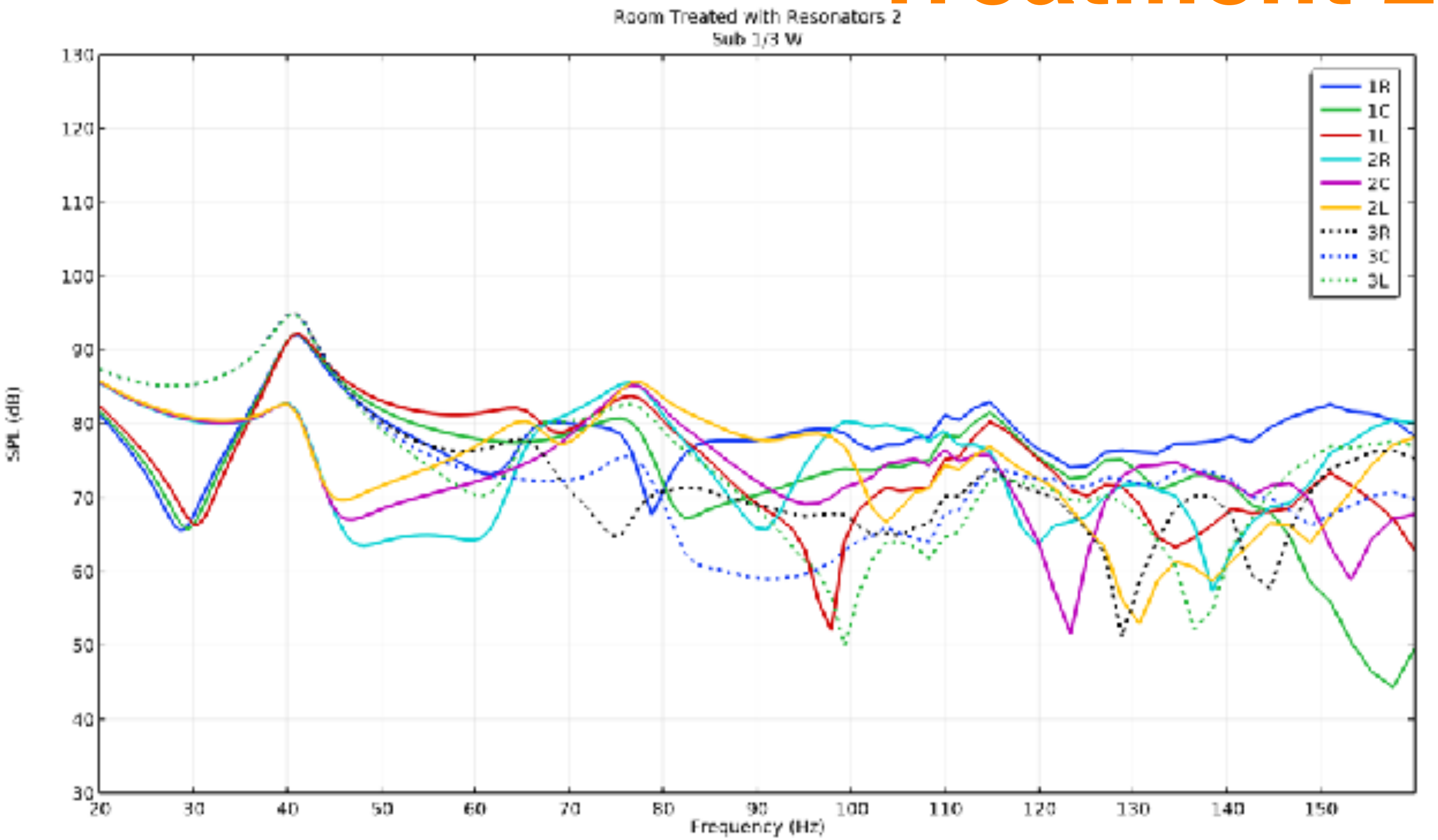
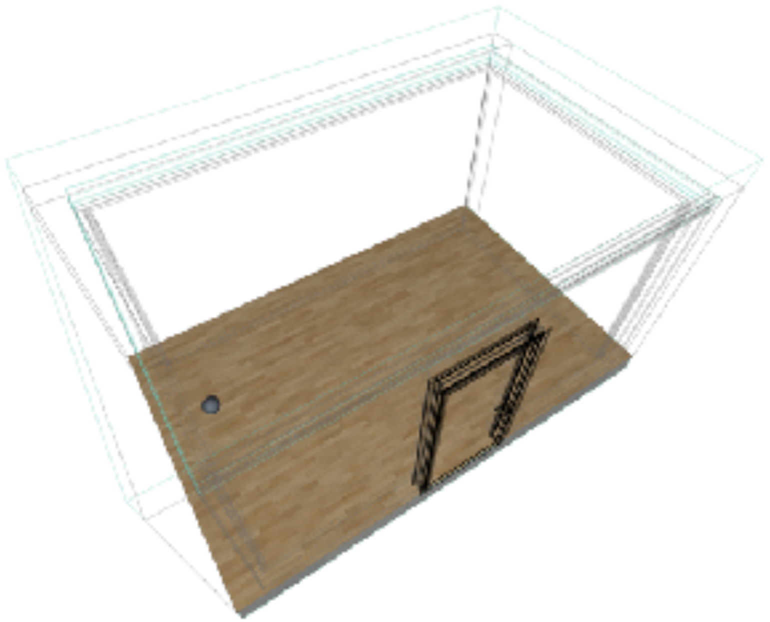
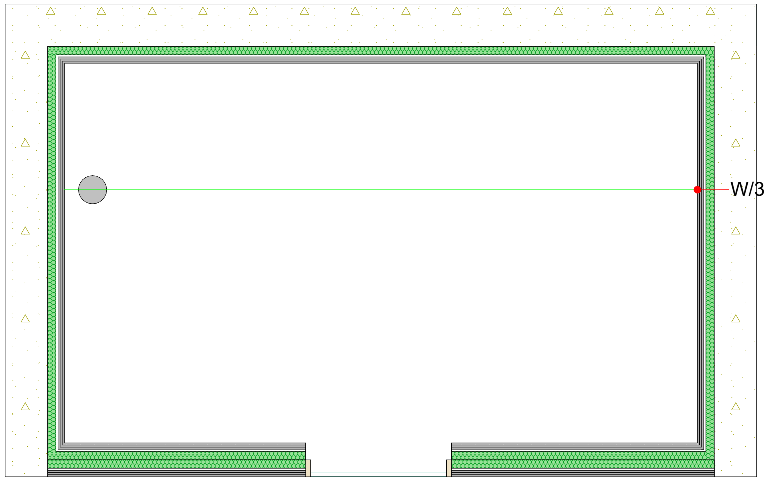
STUDIO SOUND SERVICE

Simulations - Dolby 1/3 Treatment 2







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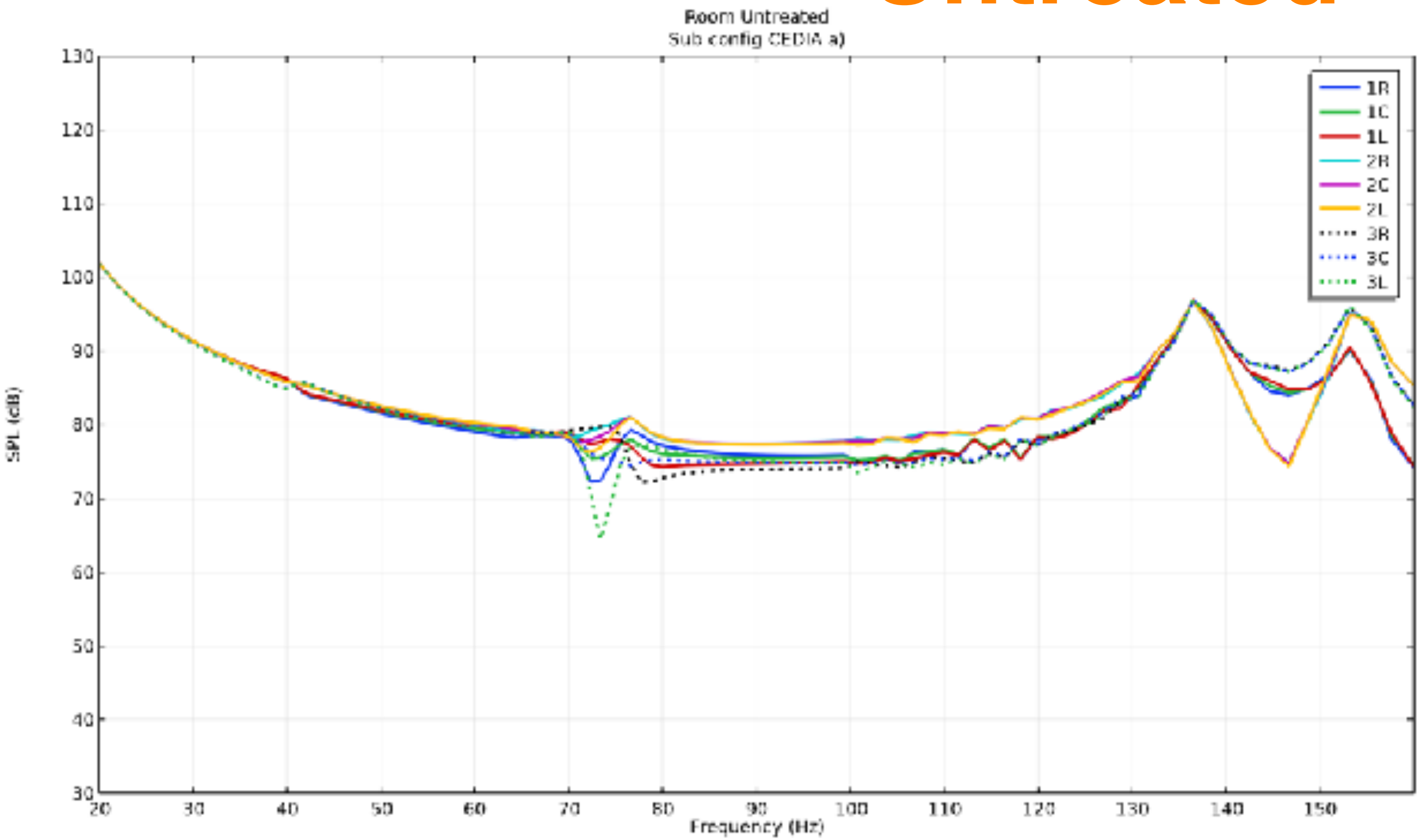
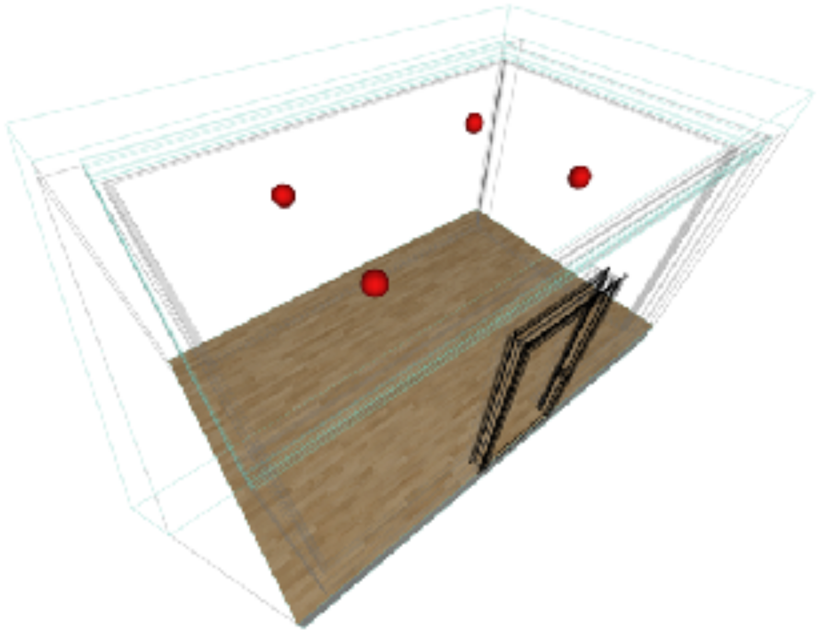
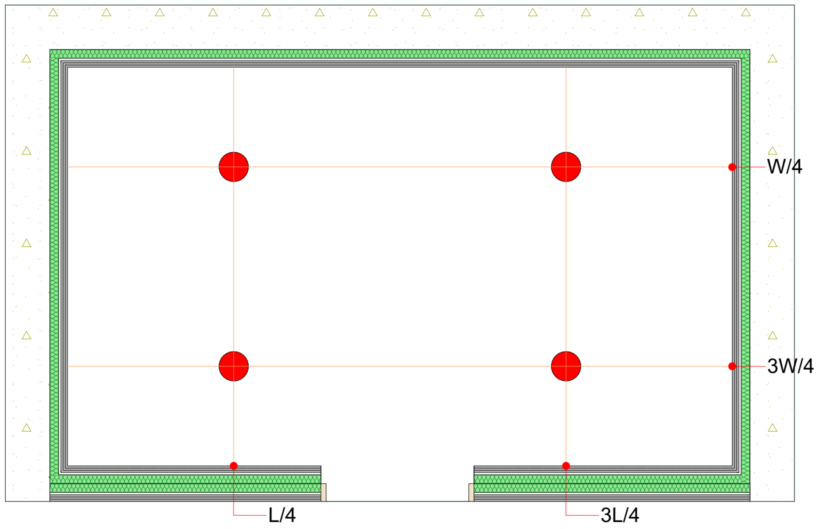
STUDIO SOUND SERVICE

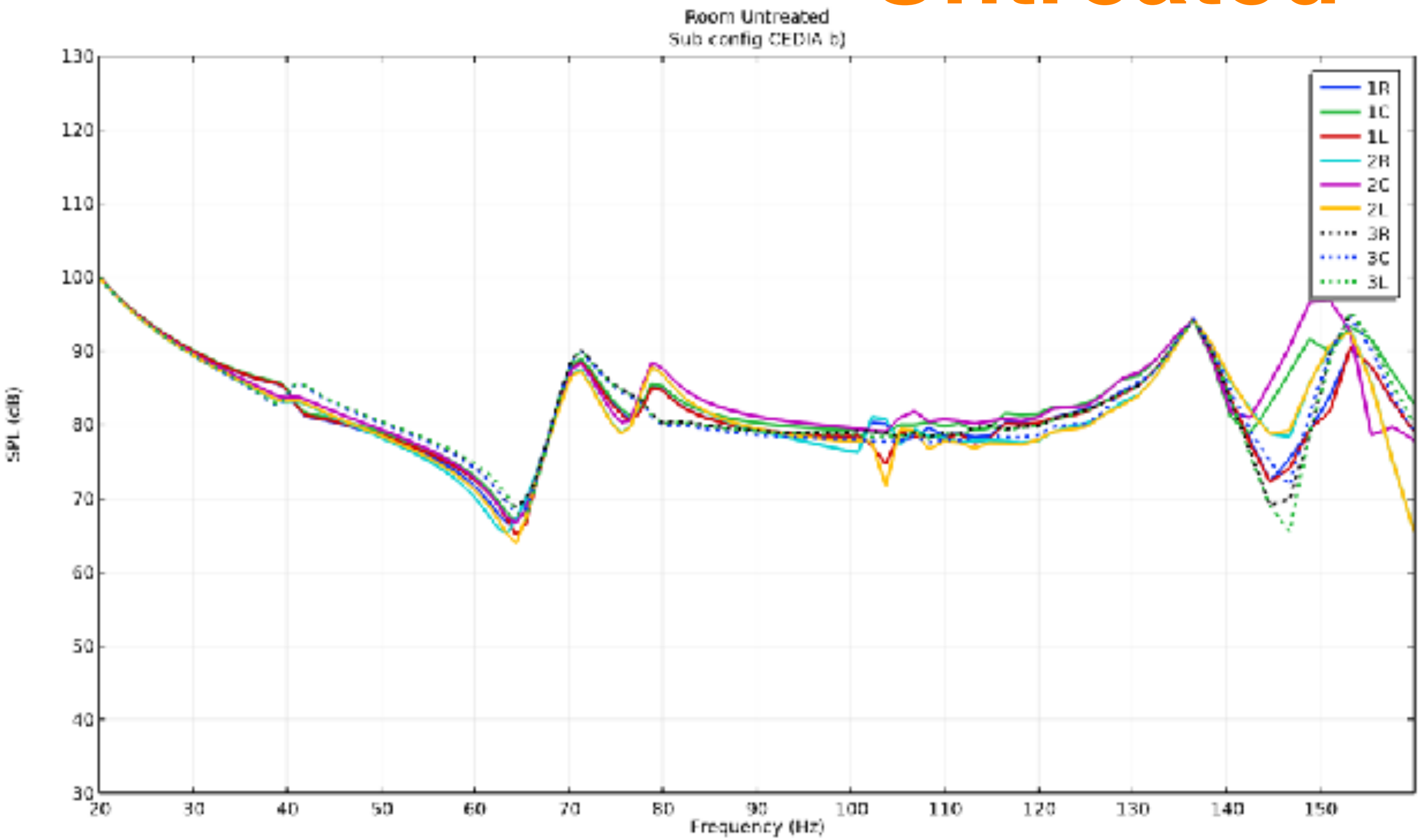
Simulations - Cedia a) Untreated

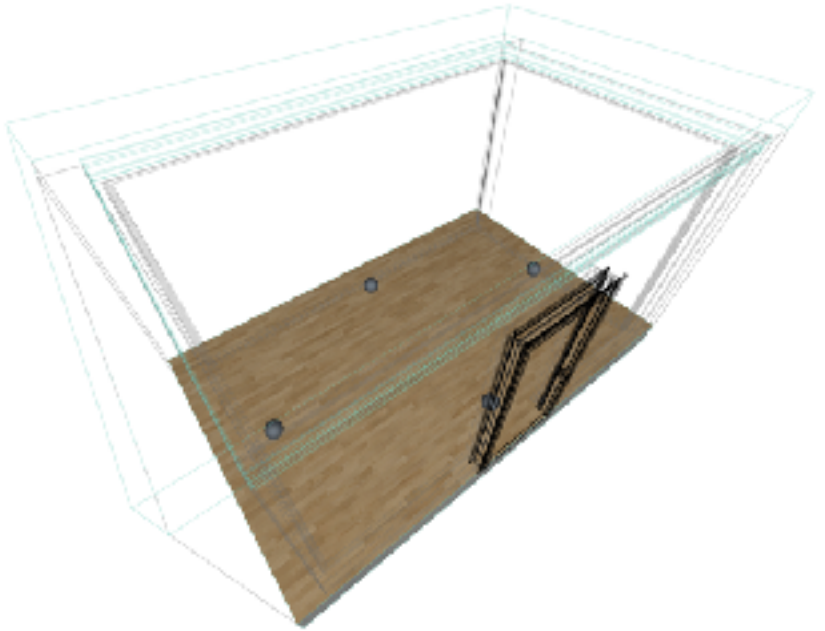


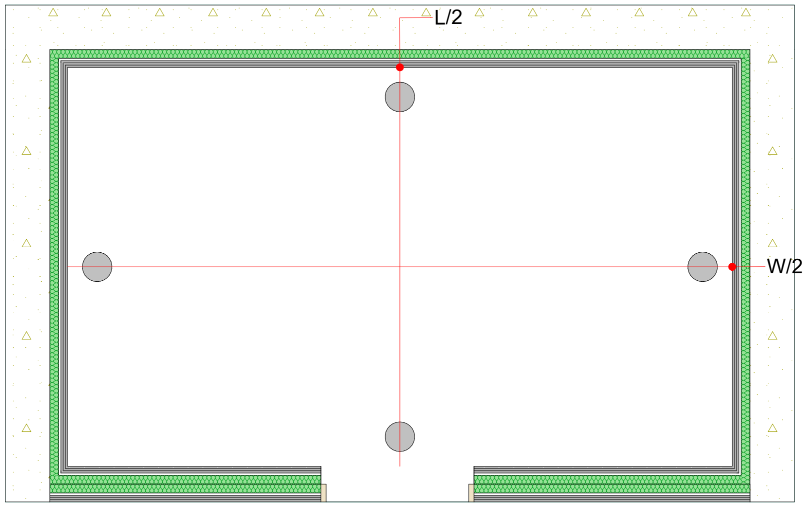




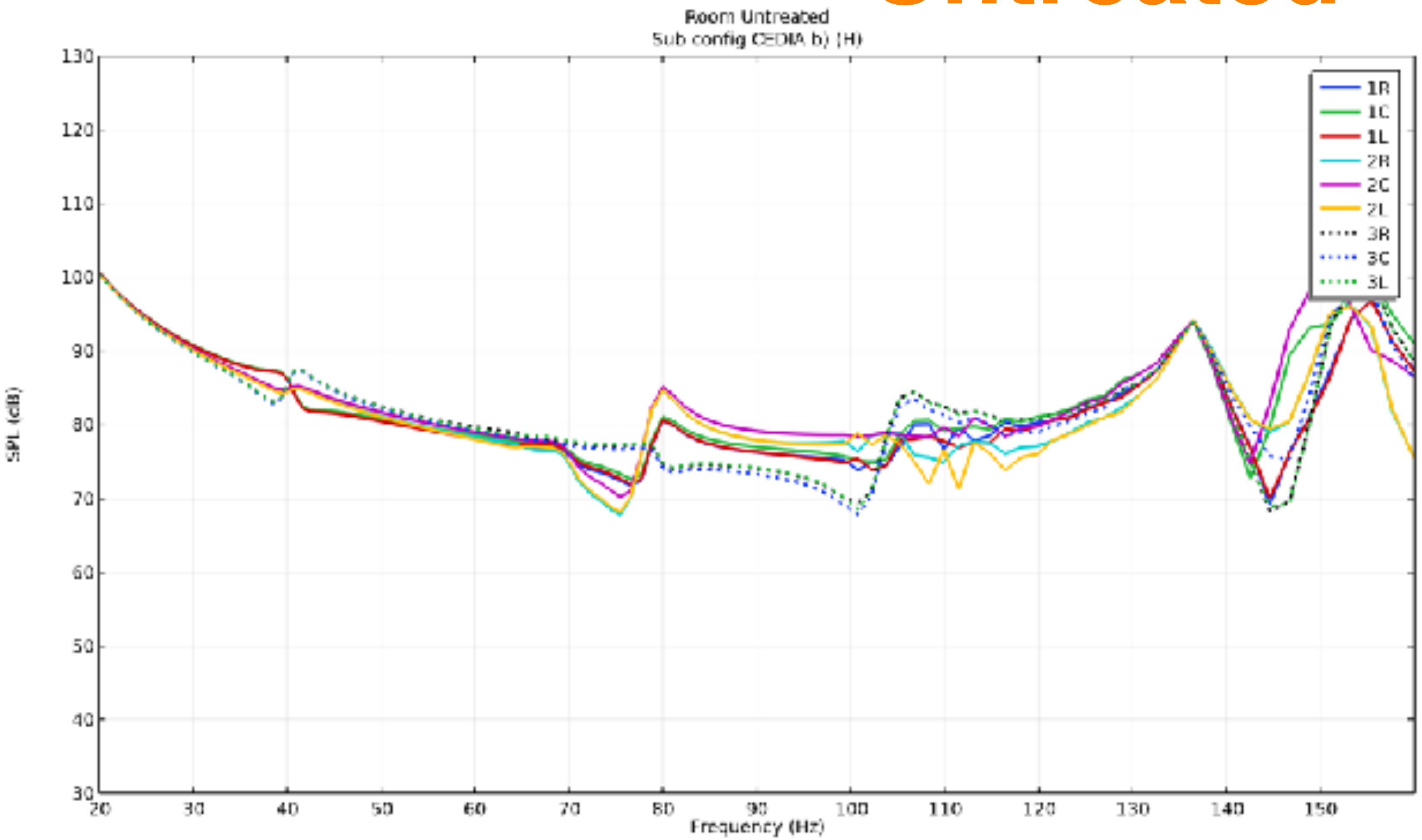
Simulations - Cedia b) Untreated

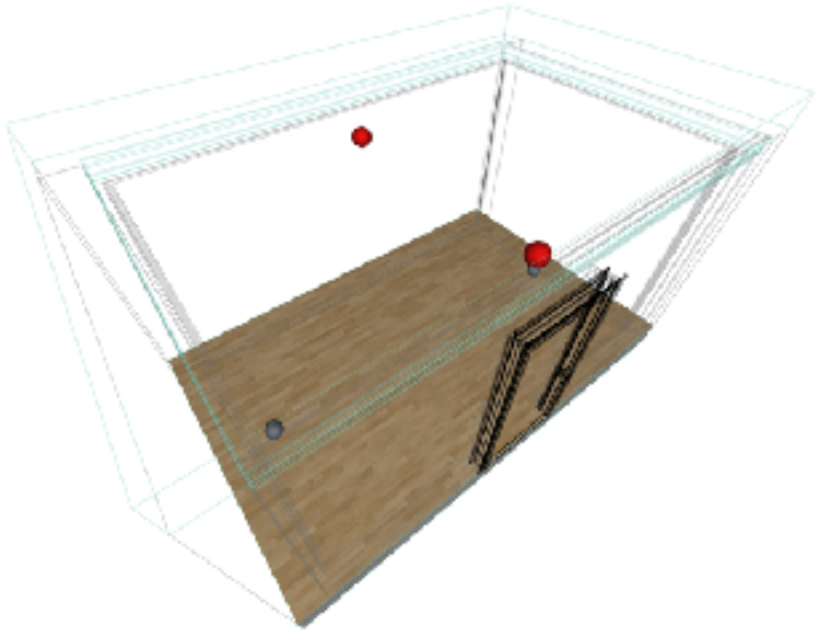


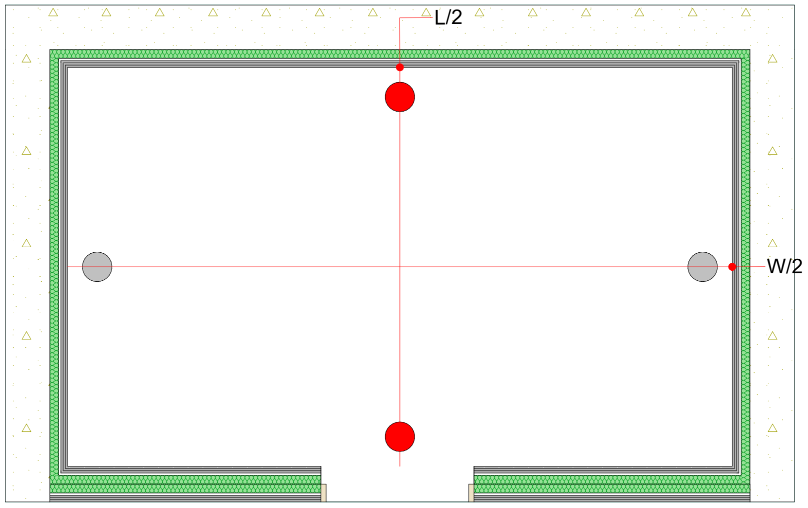




Simulations - Cedia b_h) Untreated

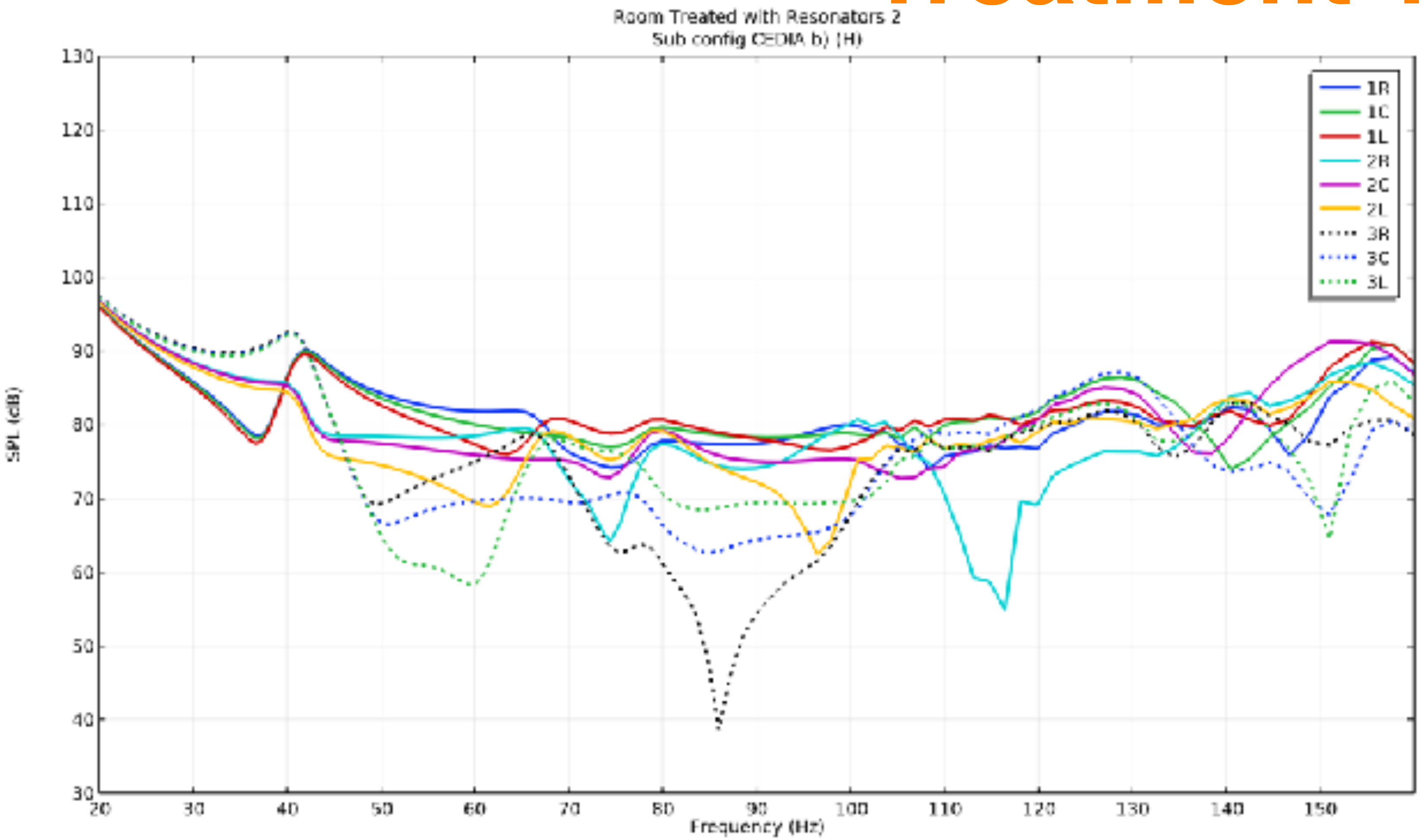


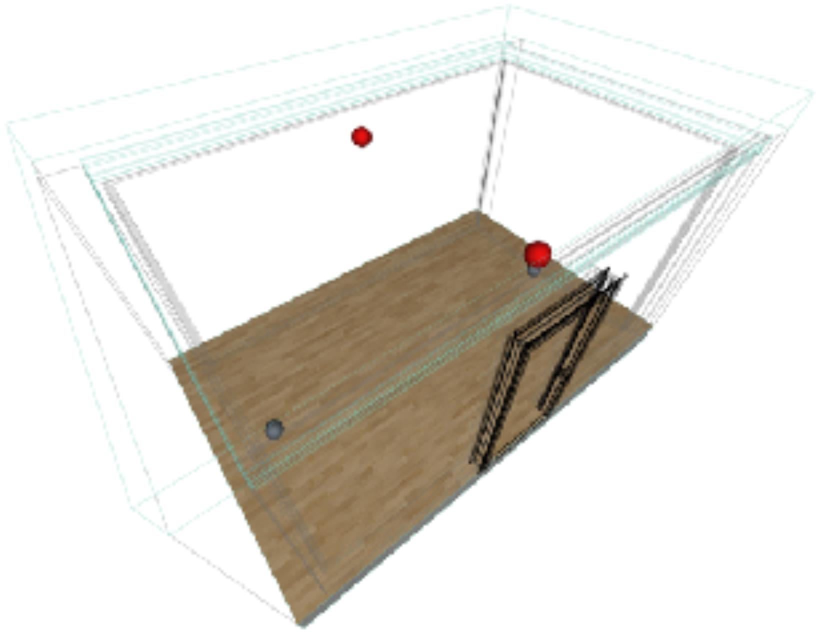


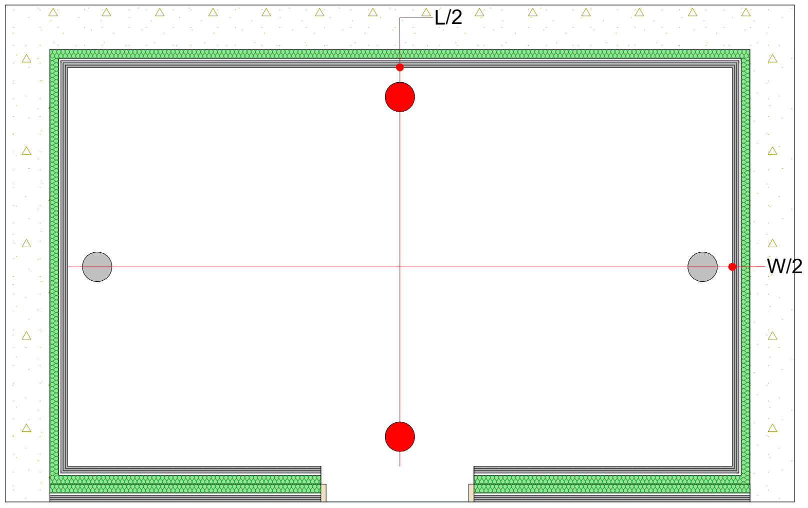


Simulations - Cedia b_h)

Treatment 1







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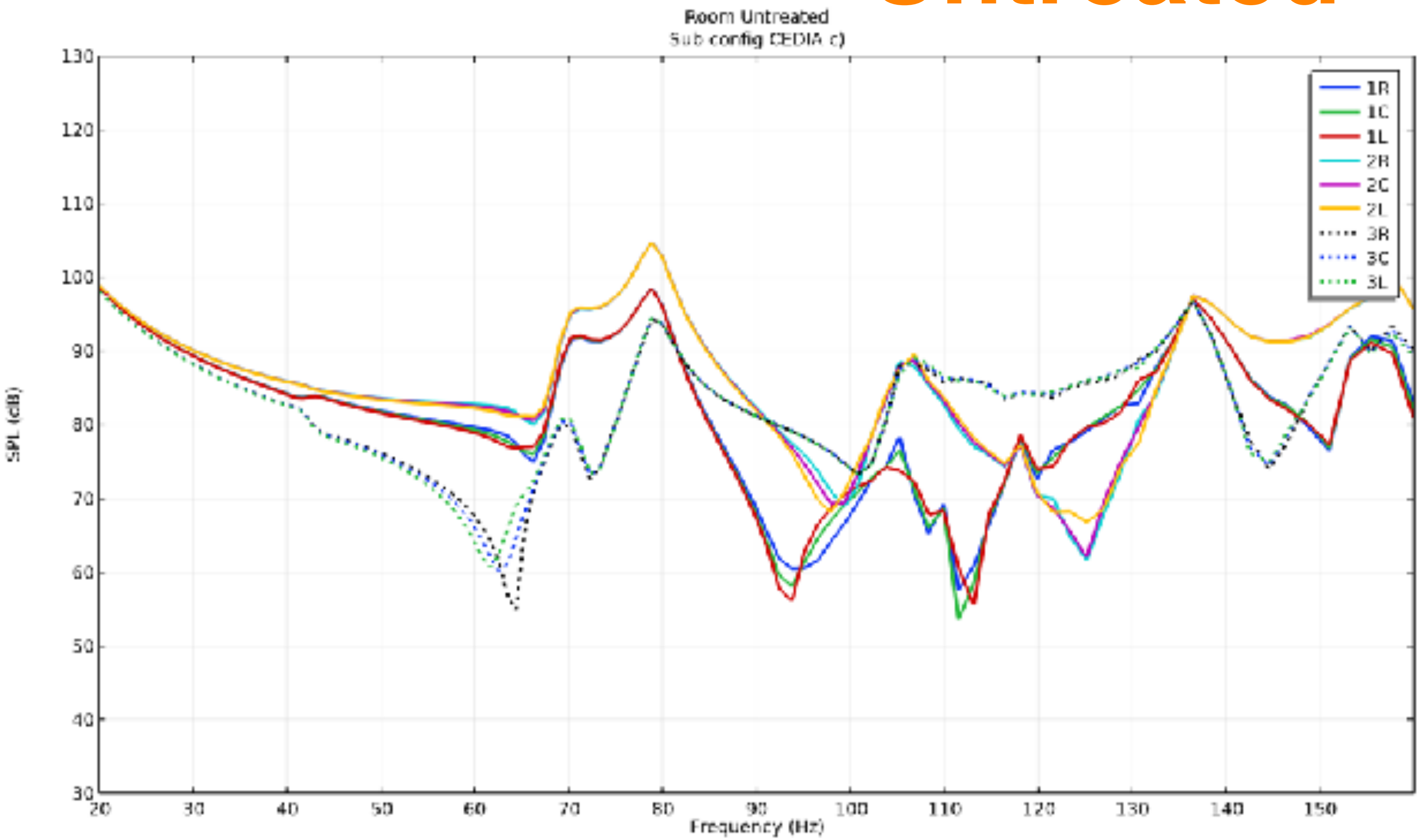
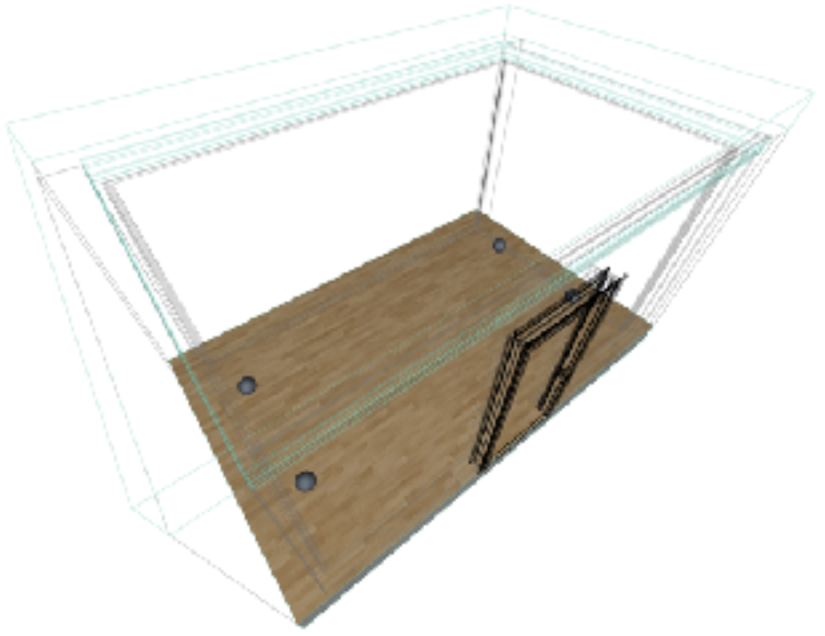
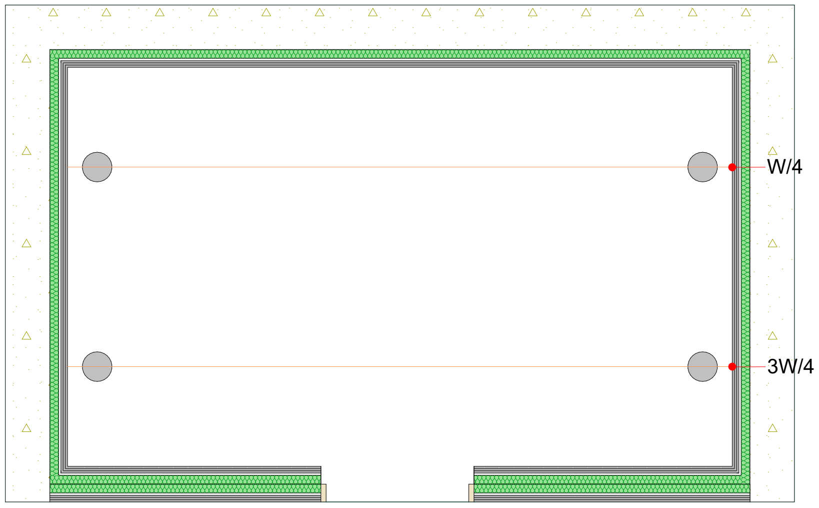
Simulations - Cedia c)

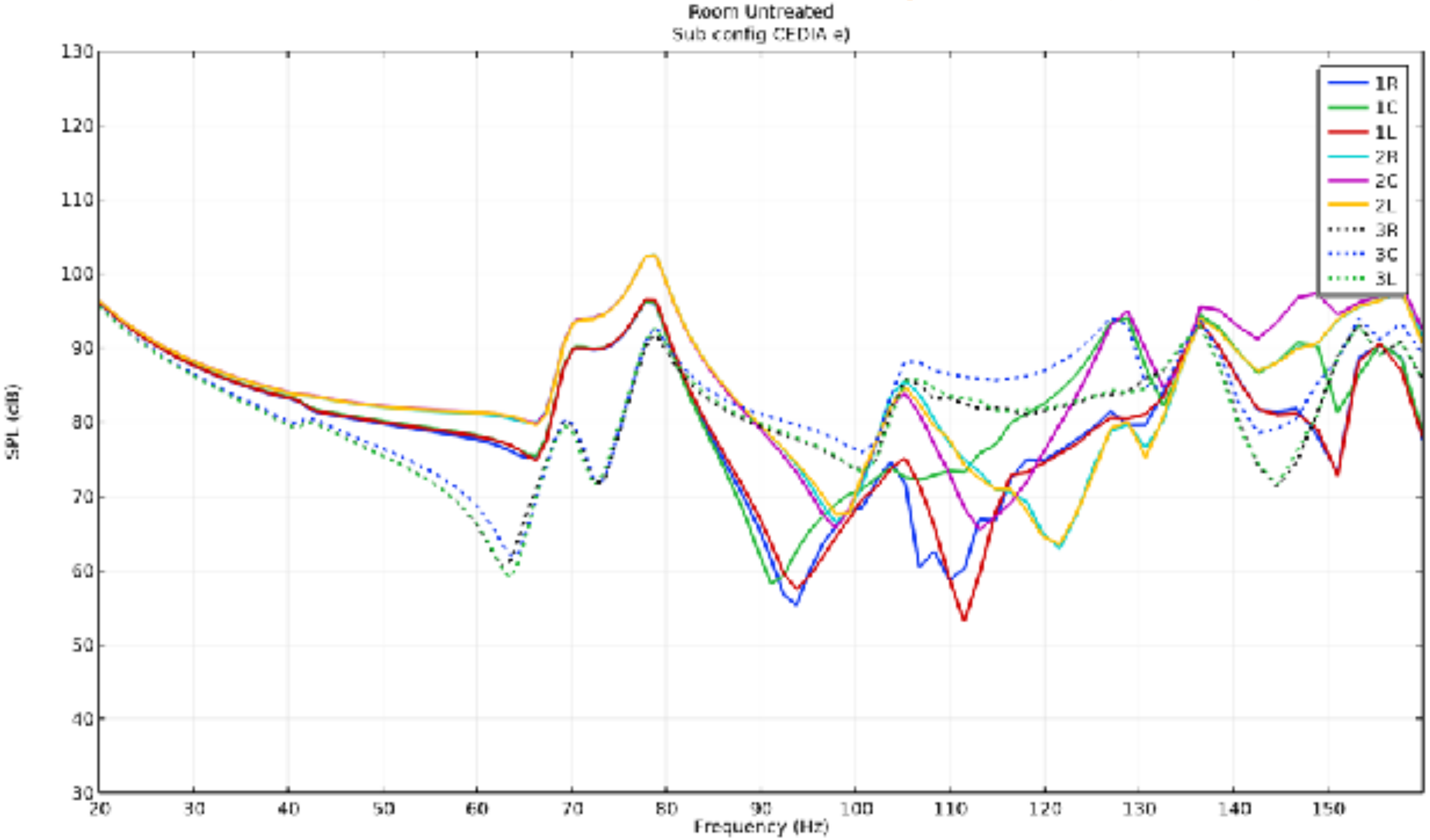
Untreated

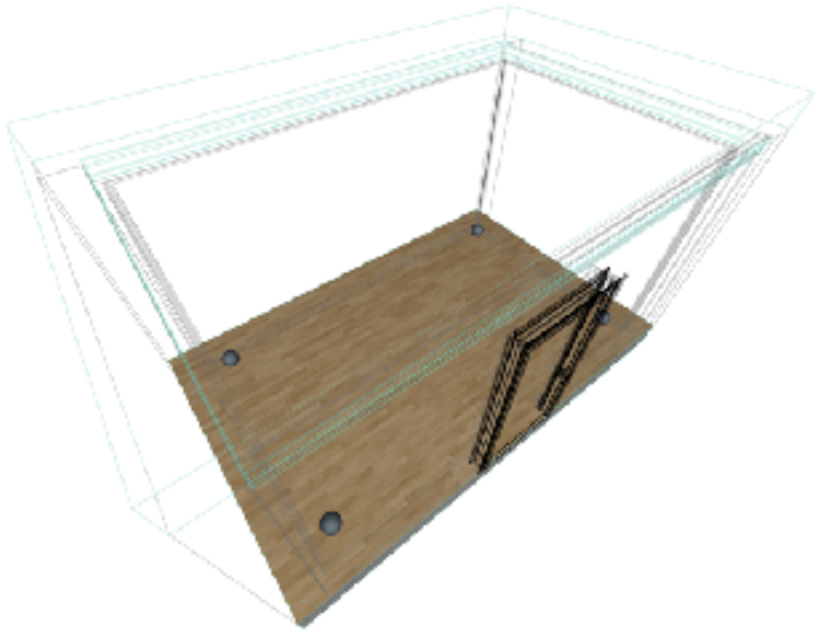


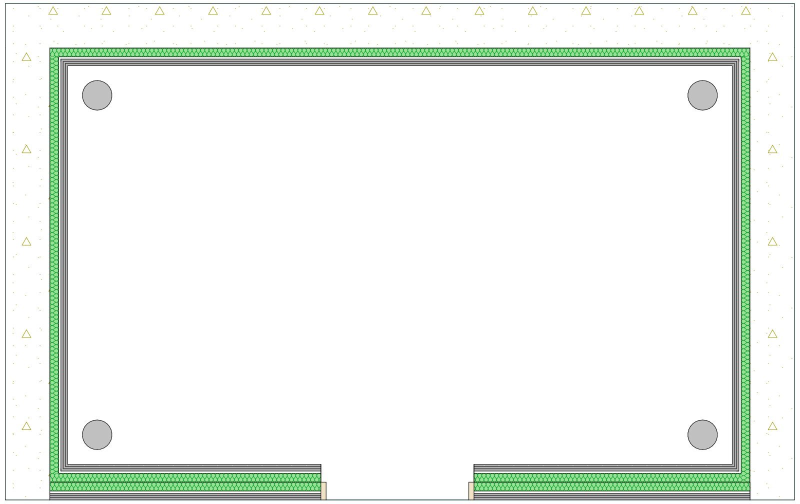




Simulations - Cedia e) Untreated







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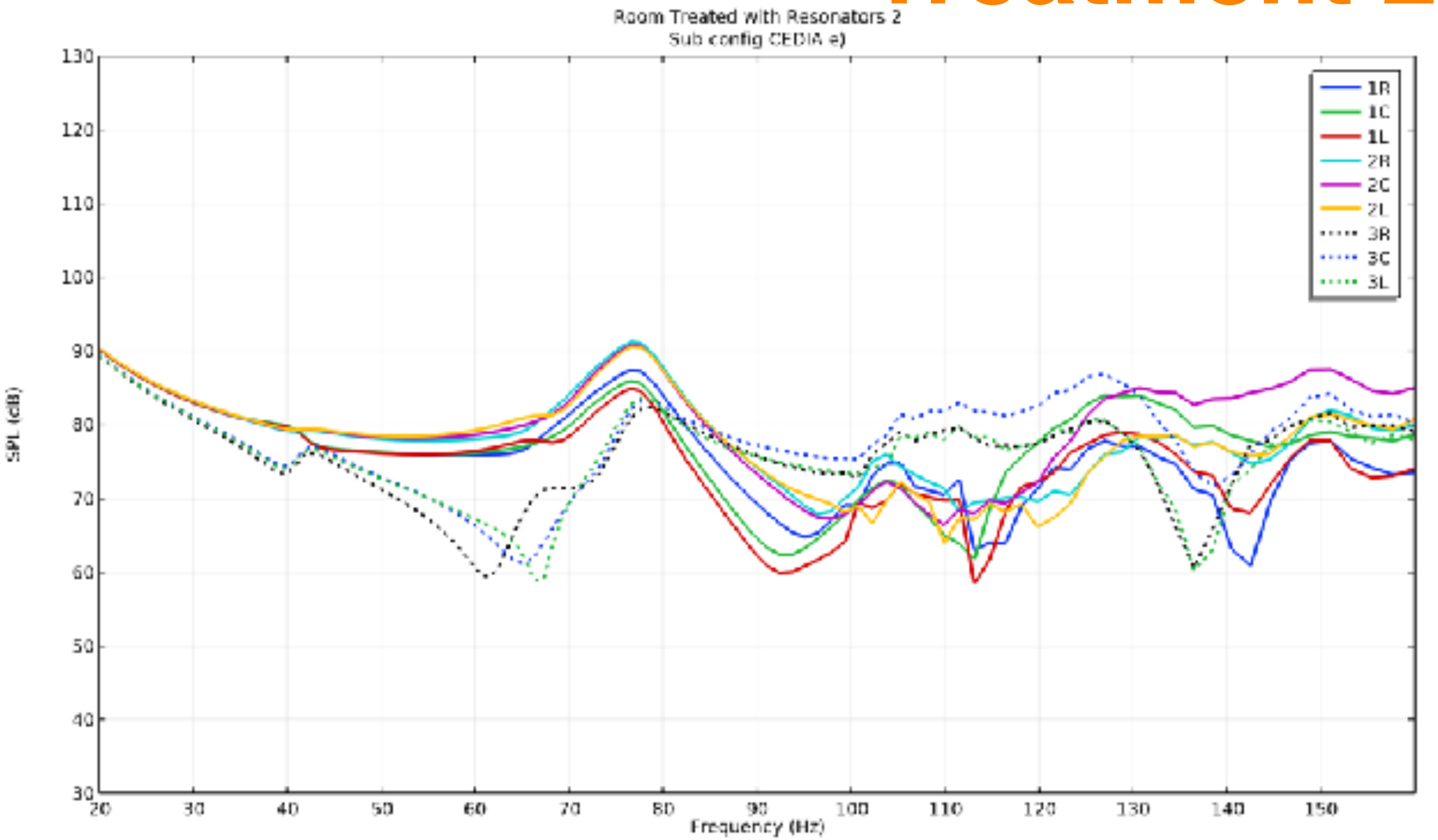
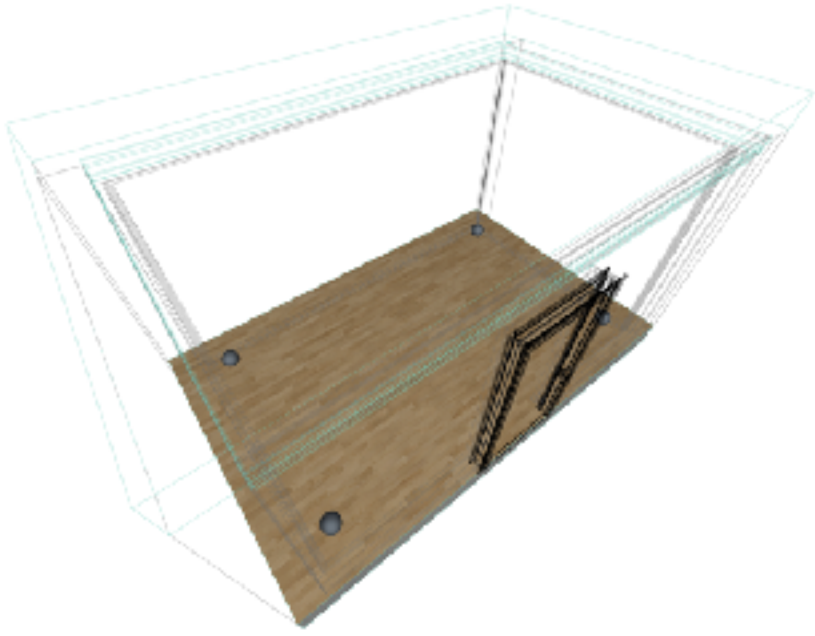
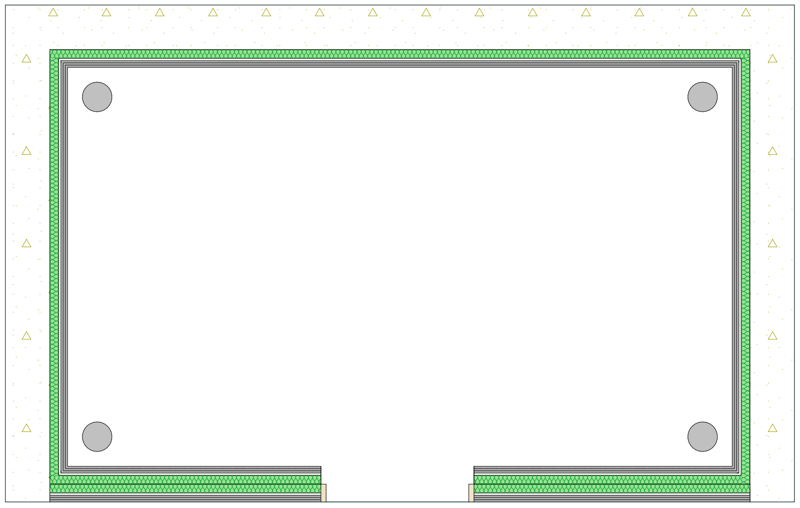
Simulations - Cedia e) Treatment 2







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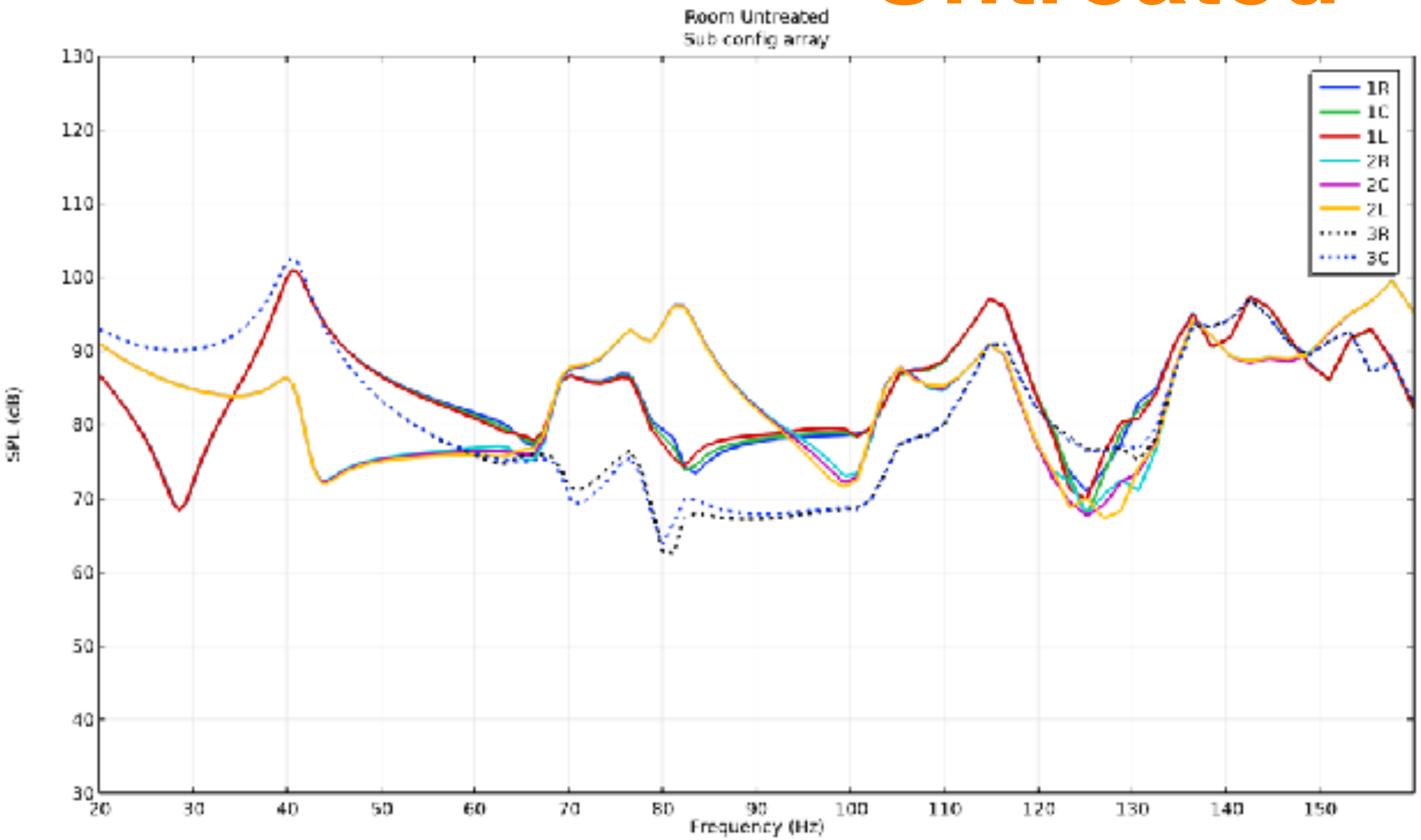
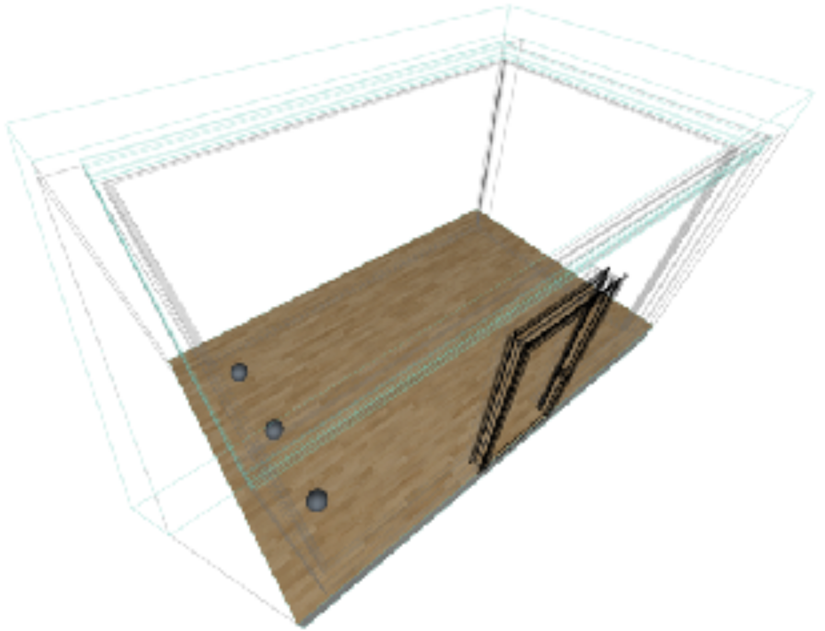
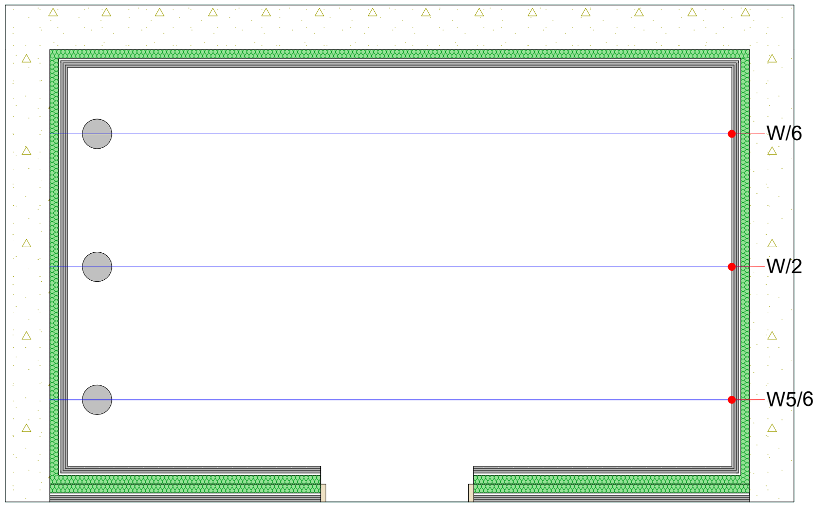
Simulations - Array Untreated







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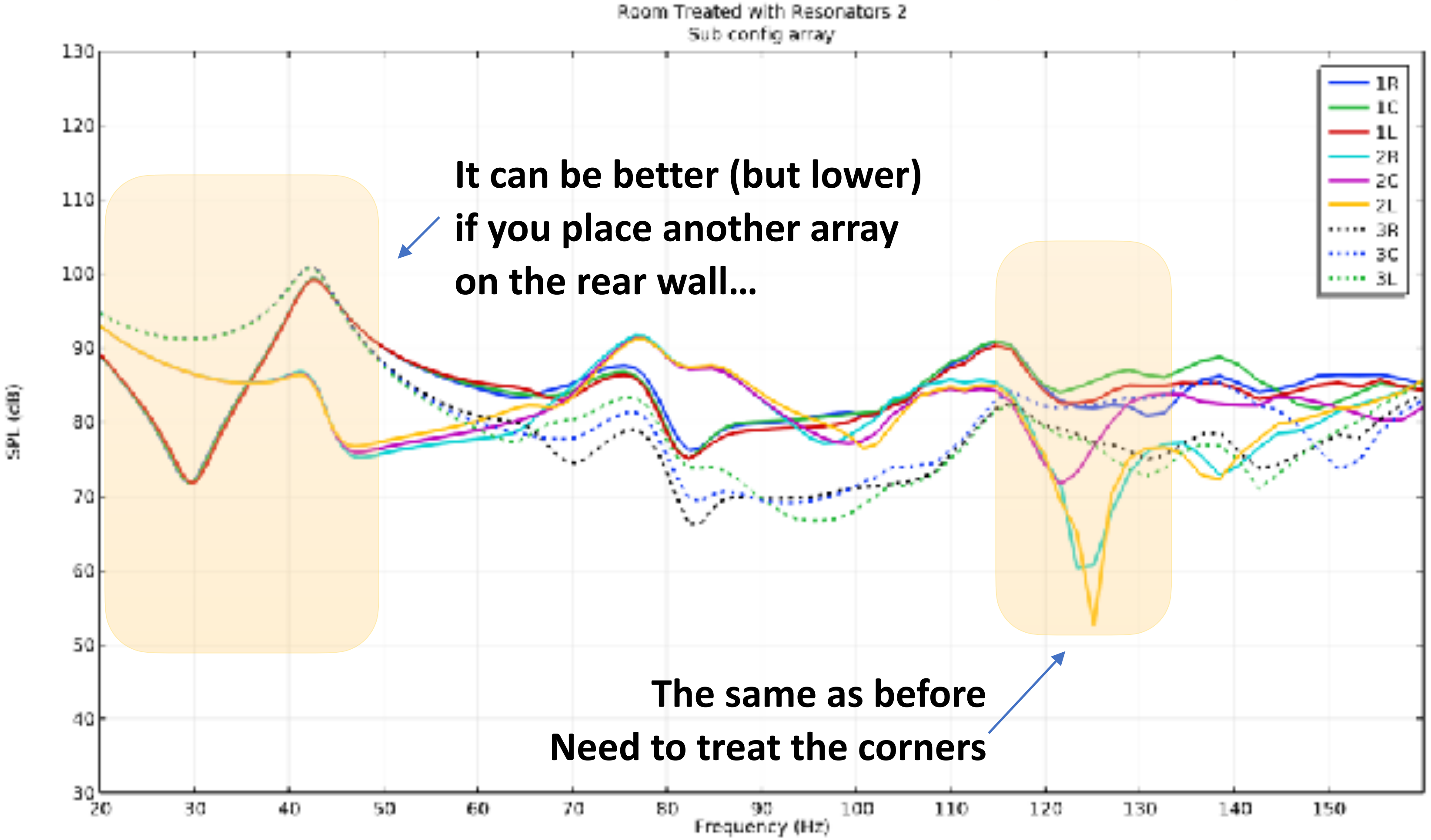
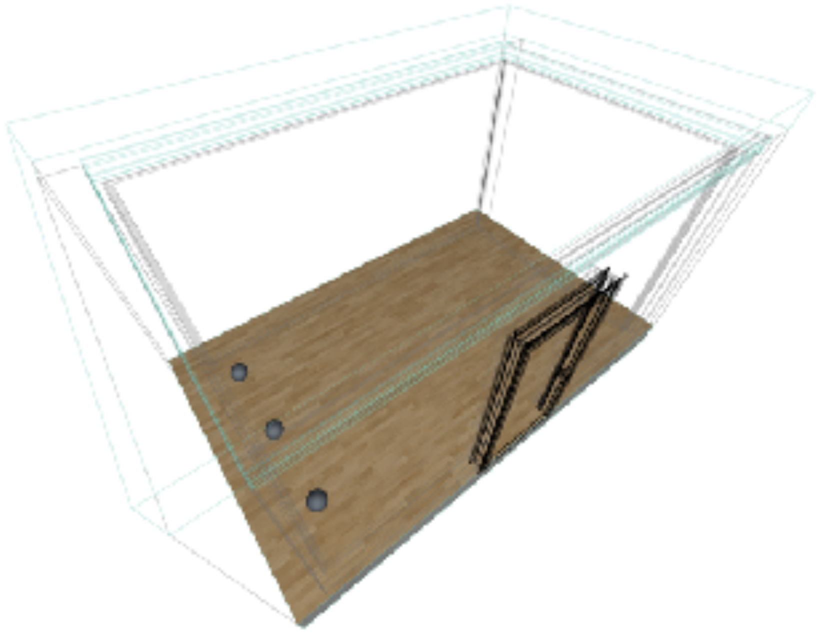
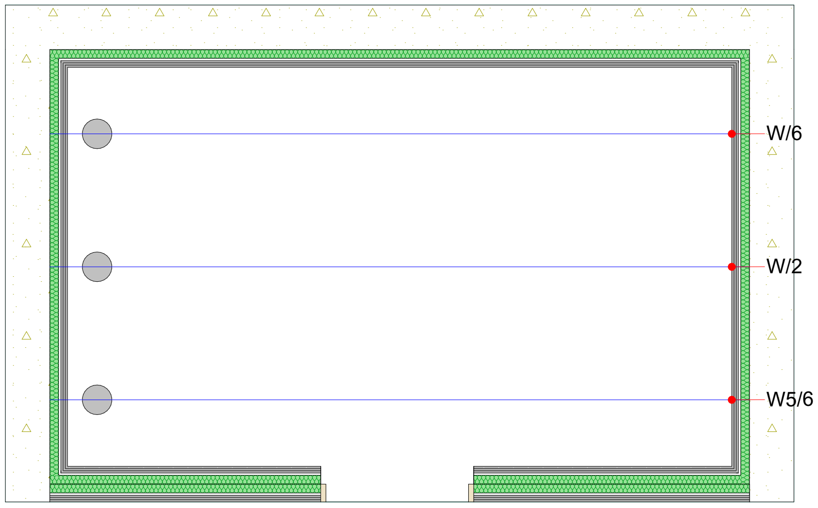
Simulations - Array Treatment 2







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Cinecittà Sala E

Roma

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Cinecittà Sala E

Roma

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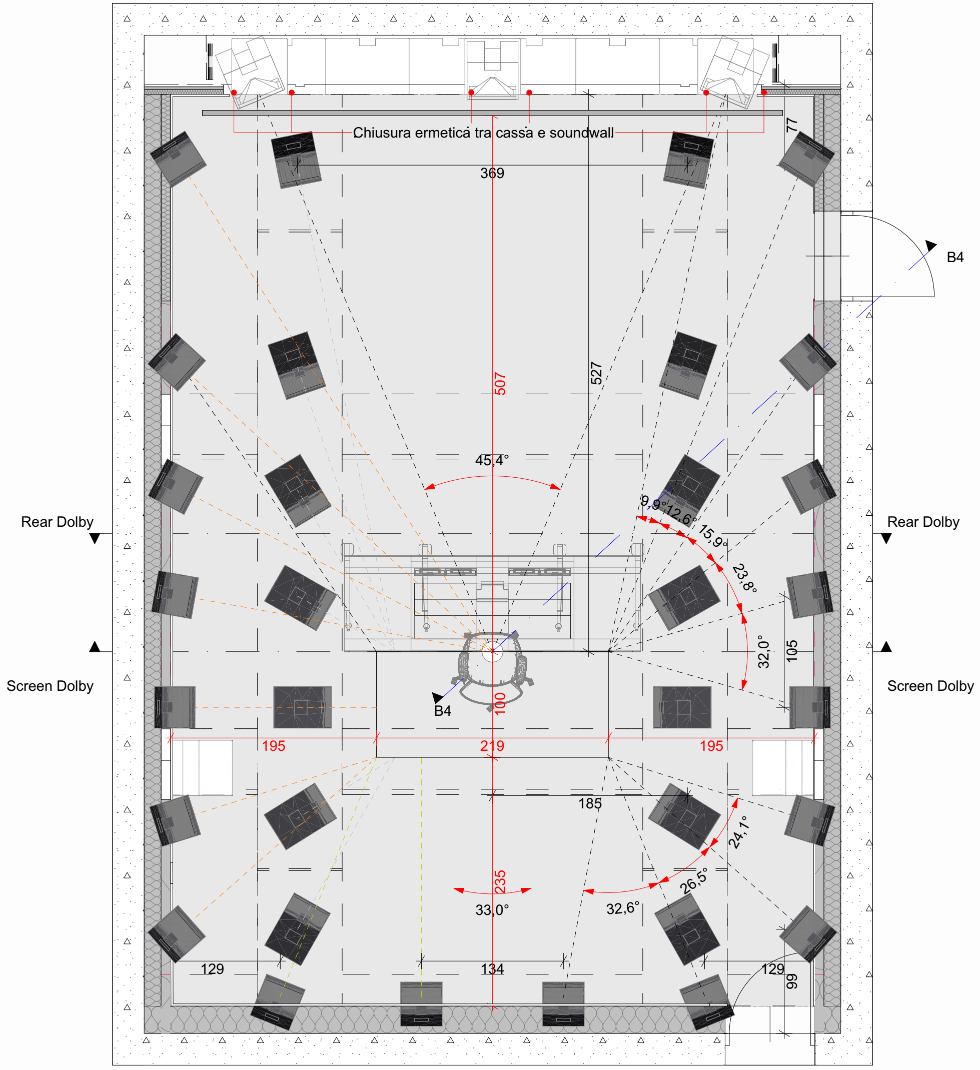
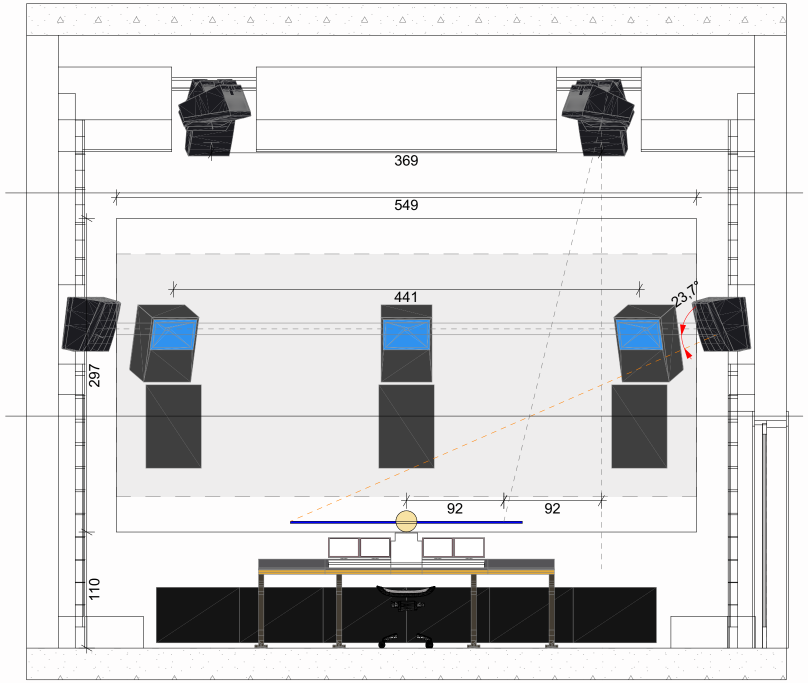
Roma



Layout

1:50



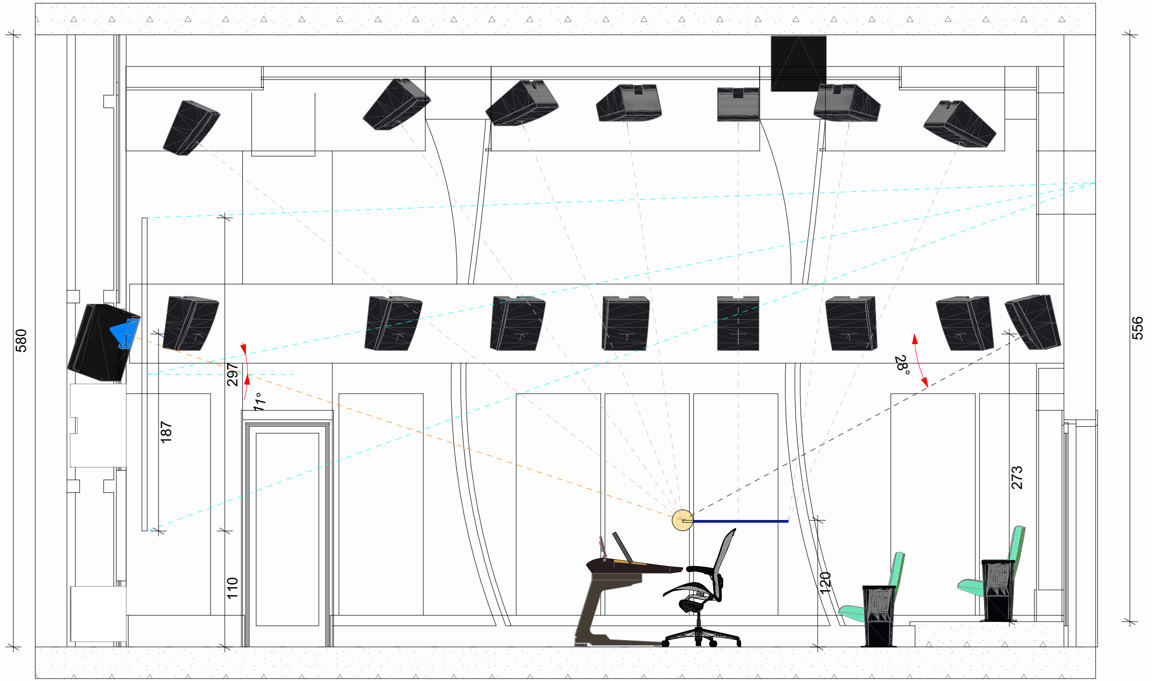
Screen elevation

1:50

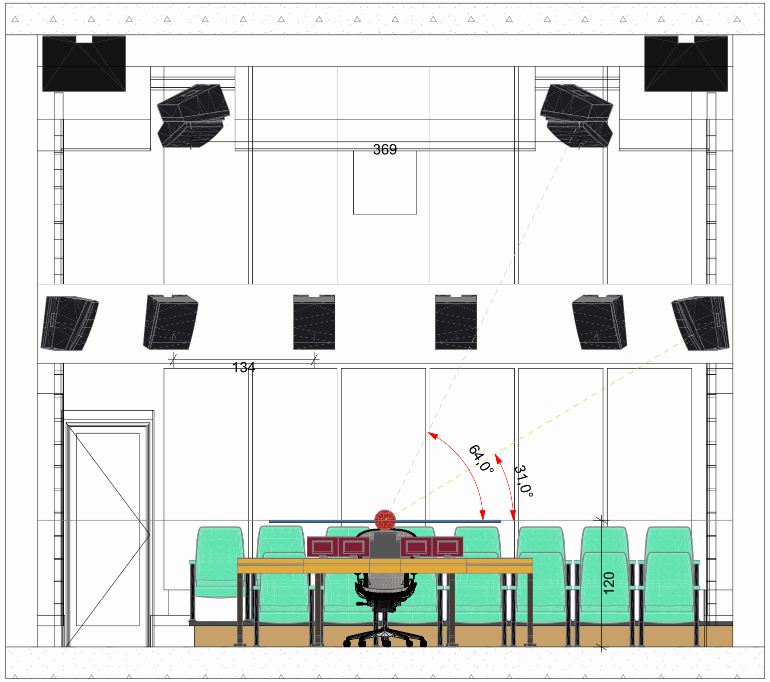
Studio Sound Service S.r.l.
Via Torricella 22/a, 50023 Impruneta (FI) Italy
info@studiosoundservice.com
Tel. +39 055 2020574
www.studiosoundservice.com

Acoustic Design: **Studio Sound Service**

Date	Drawing Number	Title	Dr. Scale	Client	Project
11/12/2023	**19 / 21**	**Dolby**	**1:50**	**Cinecittà**	**Sala E**
Revision **Definitive**		Layout and sections			



Side elevation 1:50



Rear elevation 1:50

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Tel. +39 055 2020574
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Acoustic Design: **Studio Sound Service**

Date **11/12/2023**
Revision **Definitive**

Drawing Number **20 / 21**

Title **Dolby** Sections

Dr. Scale **1:50**

Client **Cinecittà**

Project **Sala E**

DARDT Status

The tool does not ensure full approval of the selected equipment and displayed speaker positions. The design and equipment needs to be approved in conjunction with loudspeaker configuration plans by Dolby Atmos design approvers.

Room Data	(Metric)	Length (m)	Width (m)	Length of raked staging (m)	Room Height at Screen (m)	Room Height at Booth (m)
Show Label Guide		8,0	6,6	6,7	5,8	5,6

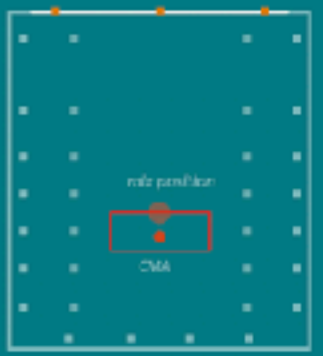
Application	Speakers per Side Wall (7 recommended)	Speakers Booth Wall (6 recommended)	Surround Subwoofers	3/5 Screen Speakers	Amping Screen Speakers
Dolby Atmos Feature Studio	7	4	2	3	bi-amped

Screen Width (m)	Screen Ratio	Screen Bottom to floor (m)
5,6	Flat	1,1
Speaker-Screen-Spacing	**Linear Spacing Distance**	**LSS Rear (m)**
1,3	1,0	1,3

Auditorium Configuration Options

Amplifier Channels Side	7	
Amplifier Channels Top	7	
Top Speakers Checkbox for equidistant spacing	7	☐
Rear Surround Pairing	☐	

Screen subwoofers, LFE clustered	☑
Screen subwoofers, LFE floor mounted	☑
Surround subwoofers behind screen	☐
Surround subwoofers mounted in joint of floor/wall or wall/ceiling	☑



Full linear spacing selected

Location	Speaker Channel	Loudspeaker Throw Distance Coordinates referenced from Mix Position: X (m)	Y (m)	Z (m)	3D distance from mix pos (m)	Speaker (Click here for screen speaker target SPL's): Speaker Model Checkbox only for active loudspeakers	Speaker Watts (Cont.)	dB SPL 1W@1m	Ω	Active Speaker: Maximum Peak SPL (dB)	Required Power Rating for Speaker selected: Watts required 102dB	Watts required for target SPL	Watts required per speaker 115dB	Headroom above target SPL (dB)	Amplifier: Amplifier Model	stereo/bridged	Ω	Watts available Single Channel driven	Amp headroom over target (dB)	Notes	Cables: Length (m)	ø (mm2)
Screen Left	L (LF)	2,5	5,3	1,8	6,2	Meyer Bluehorn System				132,1				5,3					0		25,0	
	L (HF)																		0		25,0	
Screen Centre	C (LF)		5,3	1,8	5,7	Meyer Bluehorn System				132,1				5,9					0		25,0	
	C (HF)																		0		25,0	
Screen Right	R (LF)	2,5	5,3	1,8	6,2	Meyer Bluehorn System				132,1				5,3					0		25,0	
	R (HF)																		0		25,0	
LFE	LFE		5,3	-0,9	5,3	Meyer X-400C				123,0	6 unit			5,0					0		25,0	
Surr. Subw.	SUB 1	3,0	-1,1	4,6	5,6	Meyer X-400C				128,6	1 unit			4,6				W	0		35,0	
	SUB 2	3,0	-1,1	4,6	5,6	Meyer X-400C				128,6	1 unit			4,6				W	0		35,0	
Side Surround	LSS 1	3,0	4,6	1,8	5,8	Meyer HMS-10				126,6				4,4					0		20,0	
	LSS 2	3,0	2,7	1,8	4,4	Meyer HMS-10				126,6				5,7					0		20,0	
	LSS 3	3,0	1,5	1,8	3,8	Meyer HMS-10				126,6				7,0					0		35,0	
	LSS 4	3,0	0,5	1,8	3,5	Meyer HMS-10				126,6				7,6					0		35,0	
	LSS 5	3,0	-0,5	1,8	3,5	Meyer HMS-10				126,6				7,6					0		35,0	
	LSS 6	3,0	-1,5	1,8	3,8	Meyer HMS-10				126,6				7,0					0		35,0	
	LSS 7	3,0	-2,5	1,8	4,3	Meyer HMS-10				126,6				5,9					0		35,0	
	LSS 8																		0			
	LSS 9																		0			
	LSS 10																		0			
	LSS 11																		0			
	LSS 12																		0			
	RSS 1	3,0	4,6	1,8	5,8	Meyer HMS-10				126,6				3,4					0		20,0	
	RSS 2	3,0	2,7	1,8	4,4	Meyer HMS-10				126,6				5,7					0		20,0	
	RSS 3	3,0	1,5	1,8	3,8	Meyer HMS-10				126,6				7,0					0		35,0	
	RSS 4	3,0	0,5	1,8	3,5	Meyer HMS-10				126,6				7,6					0		35,0	
	RSS 5	3,0	-0,5	1,8	3,5	Meyer HMS-10				126,6				7,6					0		35,0	
	RSS 6	3,0	-1,5	1,8	3,8	Meyer HMS-10				126,6				7,0					0		35,0	
	RSS 7	3,0	-2,5	1,8	4,3	Meyer HMS-10				126,6				5,9					0		35,0	
	RSS 8																		0			

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2026 new approach
Using Treble

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Donato Masci

2026 new approach: using Treble

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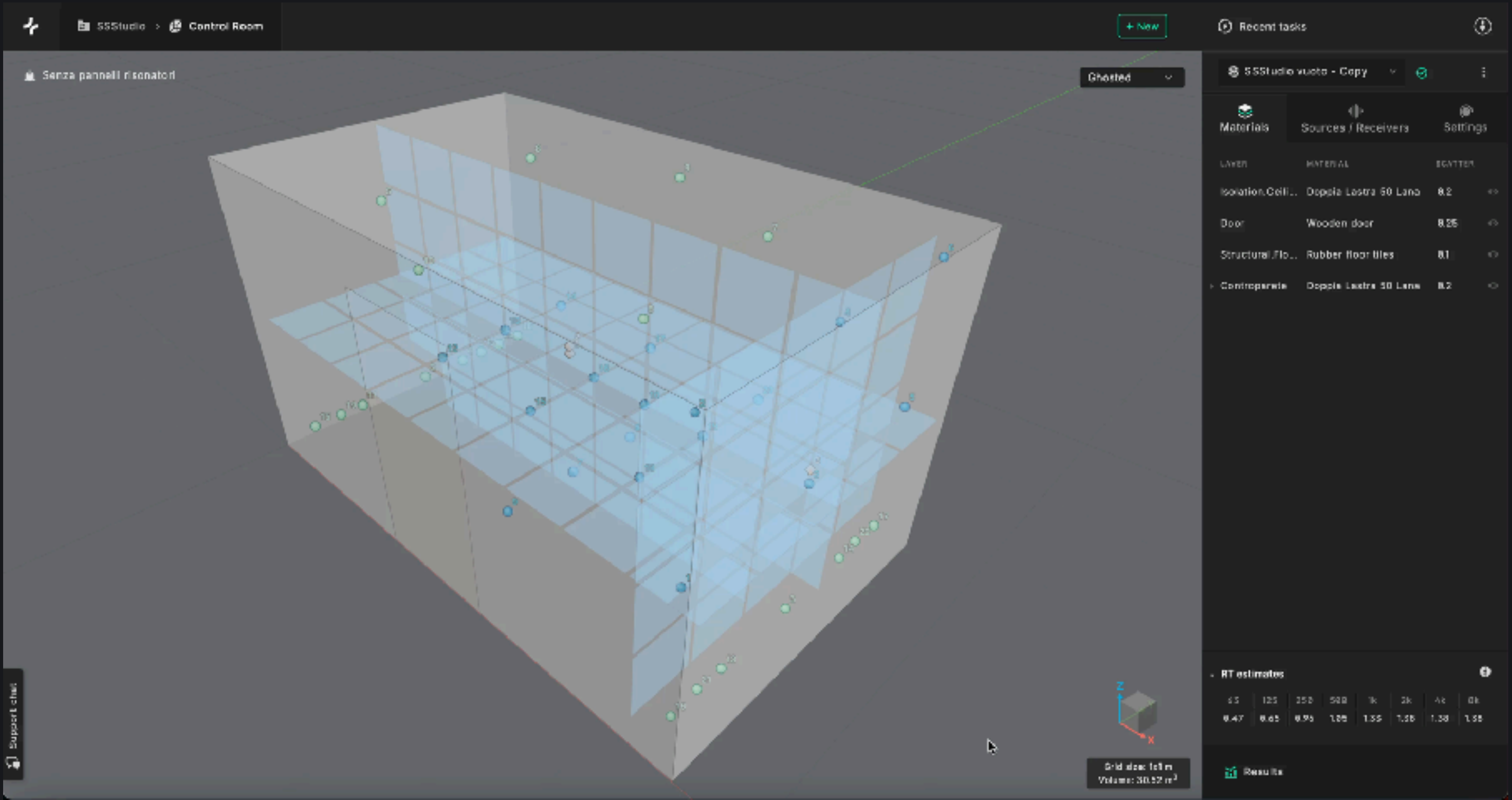


Treble simulation

PROCEDURE

- Build the model in treble
- Assign materials from database → Database has some plasterboard values (alpha + impedance), but every construction is different in terms of impedance
- Look at the RT values and compare with the measured ones
- Tune the materials in order to reach a similar RT value → Changing RT leads to change the impedance. So let Treble algorithm works for you…
- Compare the FR with the measured ones → Next slide!
- **Model tuned!**

Create new material

MATERIAL NAME

MATERIAL CATEGORY

Default scattering 0,3

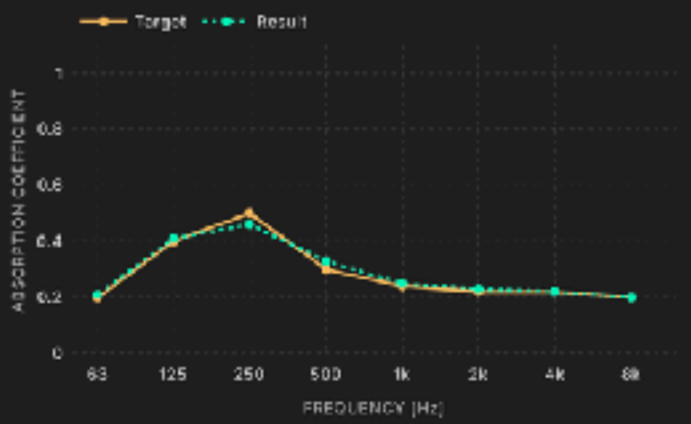
MATERIAL DESCRIPTION (OPTIONAL)

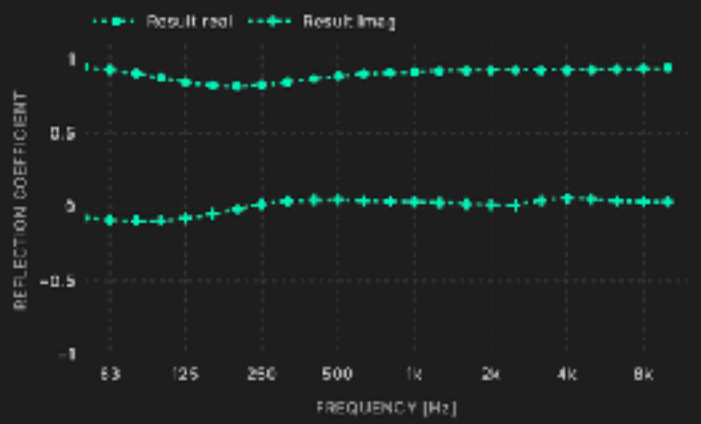
Material import / input | Porous material builder (Beta)

Full octave absorption | Surface impedance | Reflection coefficient

Absorption coefficient (Random Incidence) | Upload file

Frequency (Hz)	63	125	250	500	1k	2k	4k	8k
Target	0,2	0,4	0,5	0,3	0,24	0,22	0,22	0,20
Result	0.21	0.41	0.46	0.33	0.25	0.23	0.22	0.2





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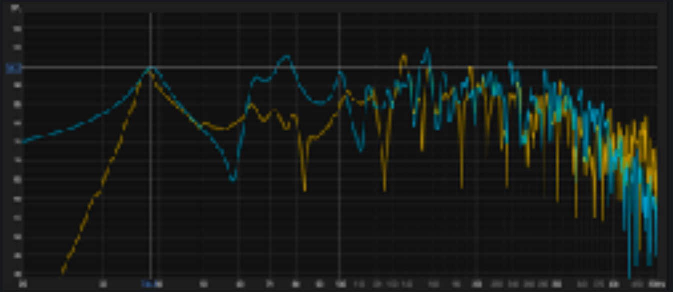
FR: Treble simulations vs measurements



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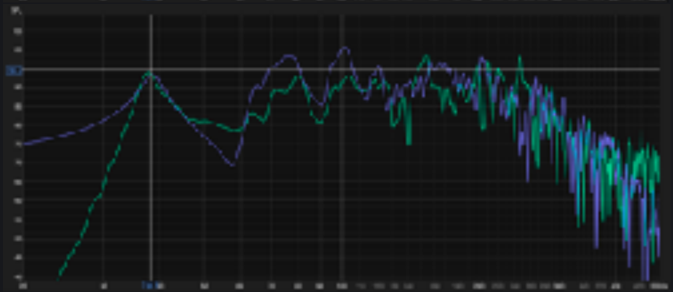

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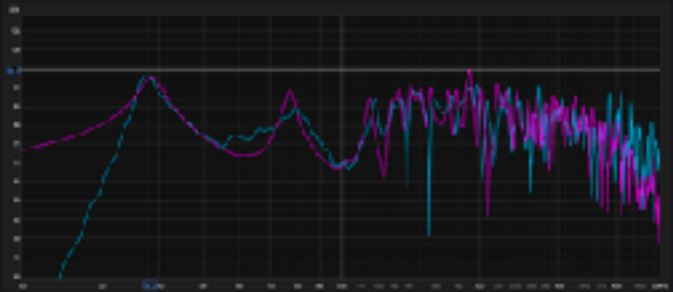

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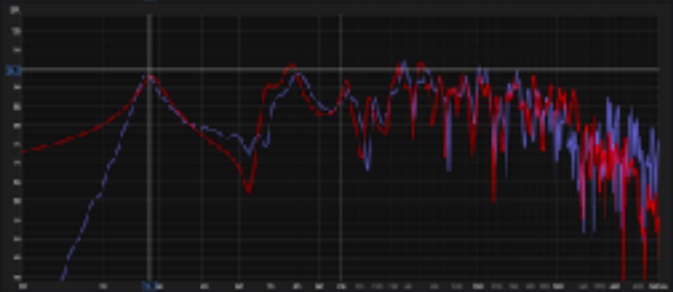

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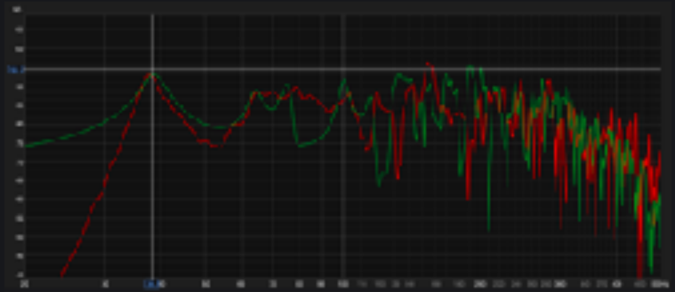

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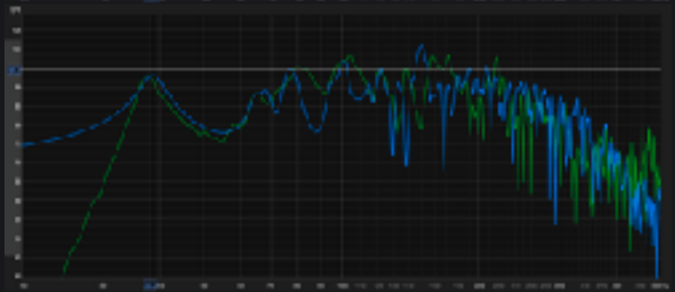

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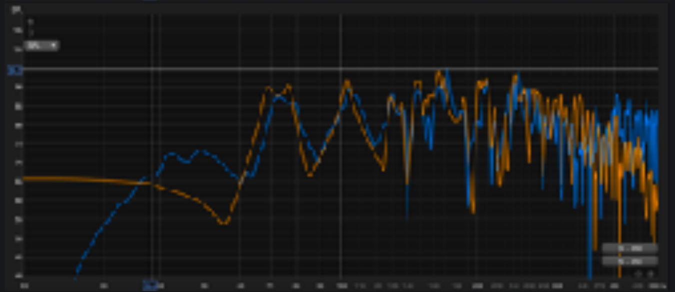

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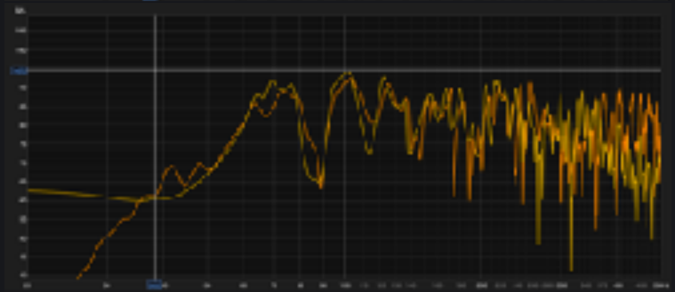

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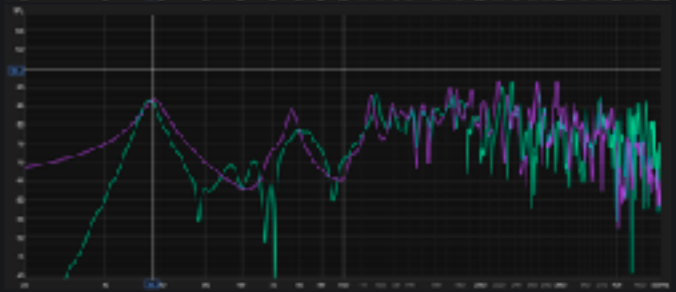

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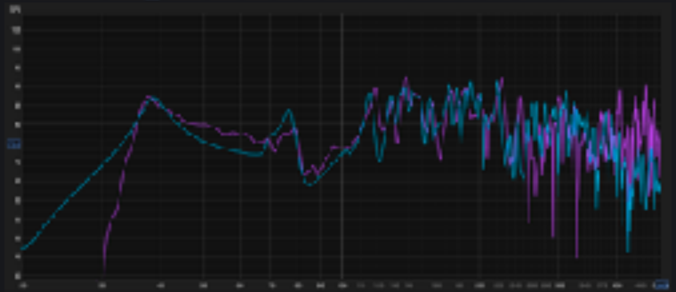

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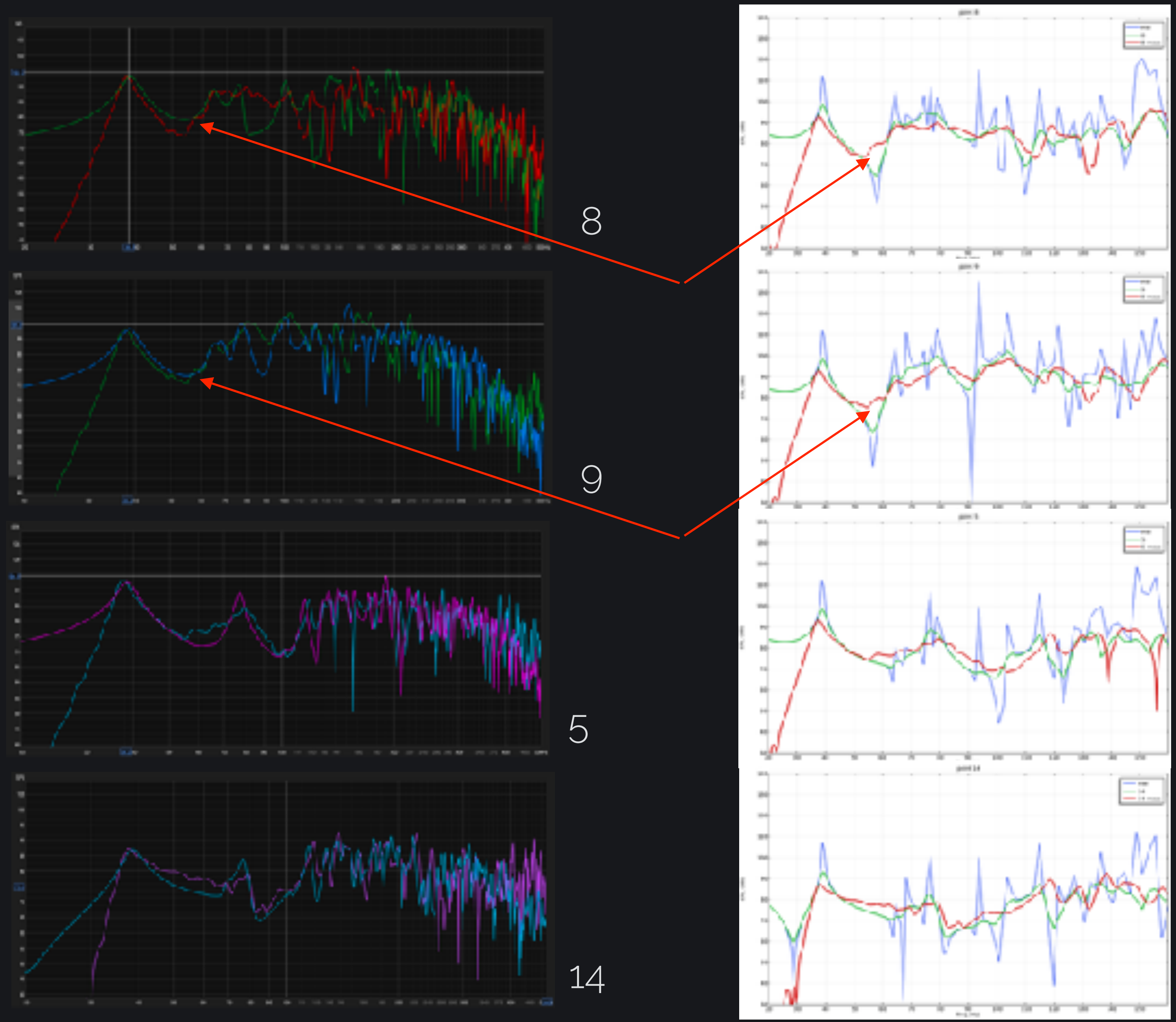
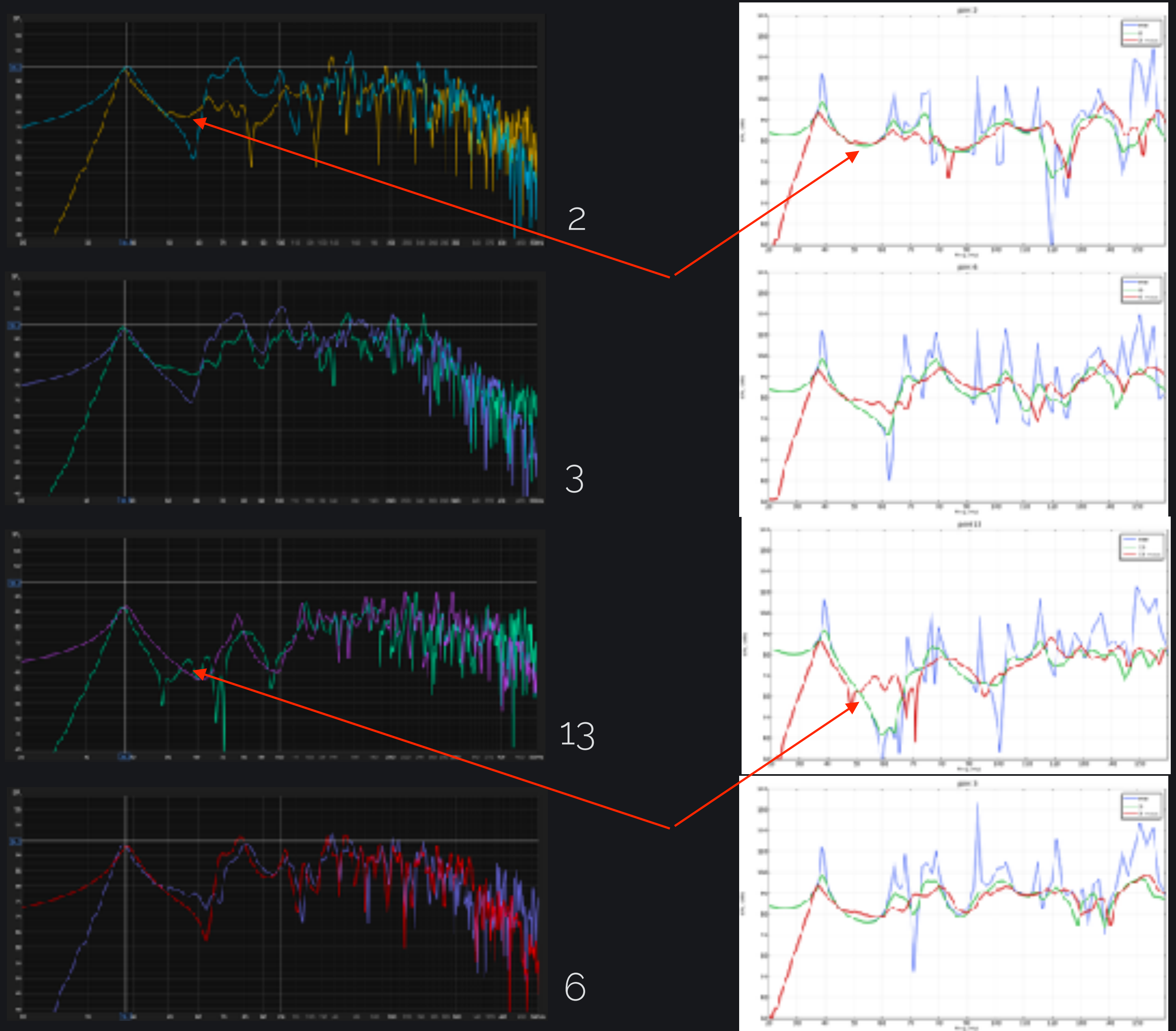
FR: Treble simulations vs measurements

Best results



Worst results



In this case is always better than Comsol simulation

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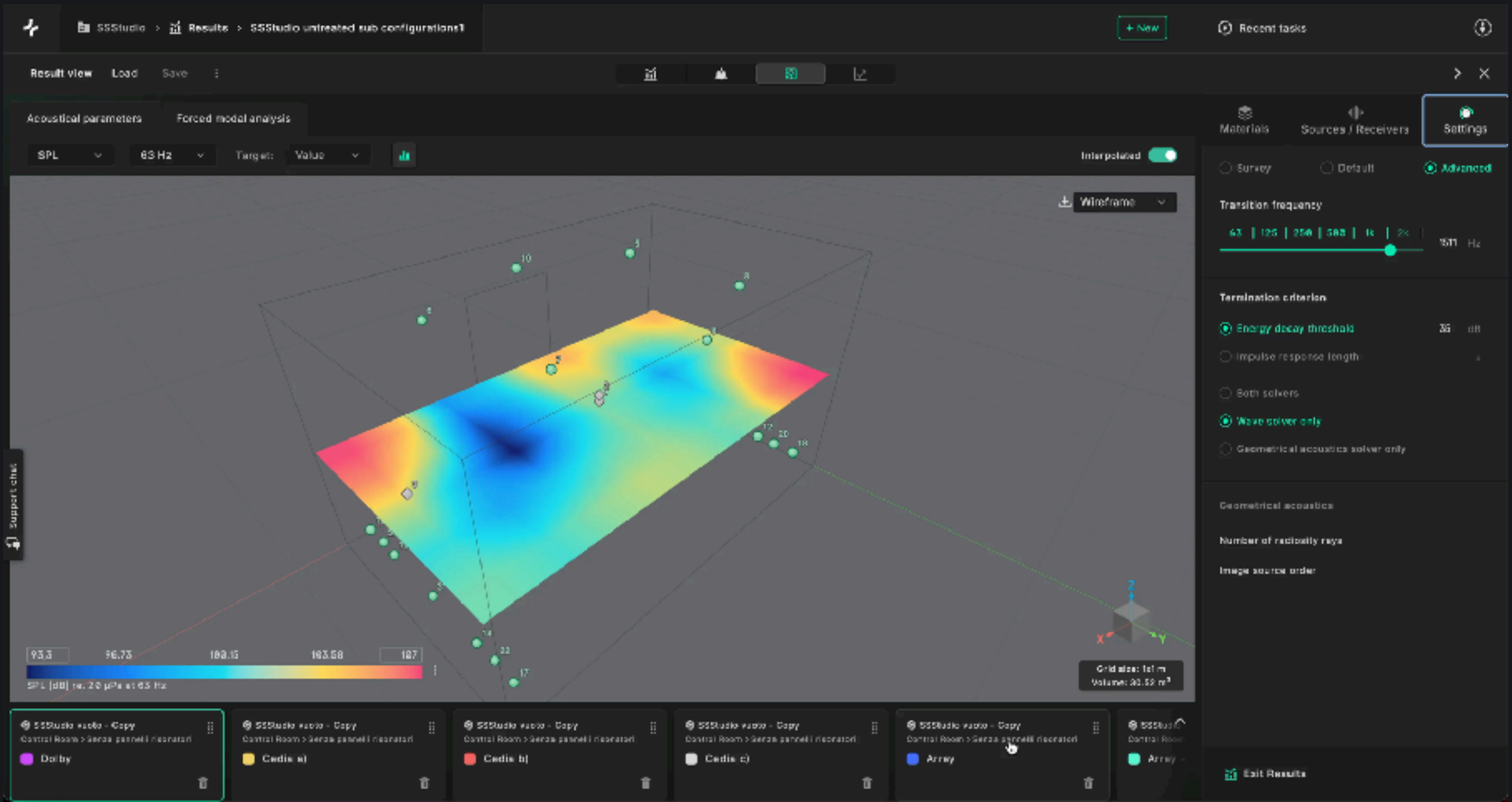
2026 new approach: using Treble



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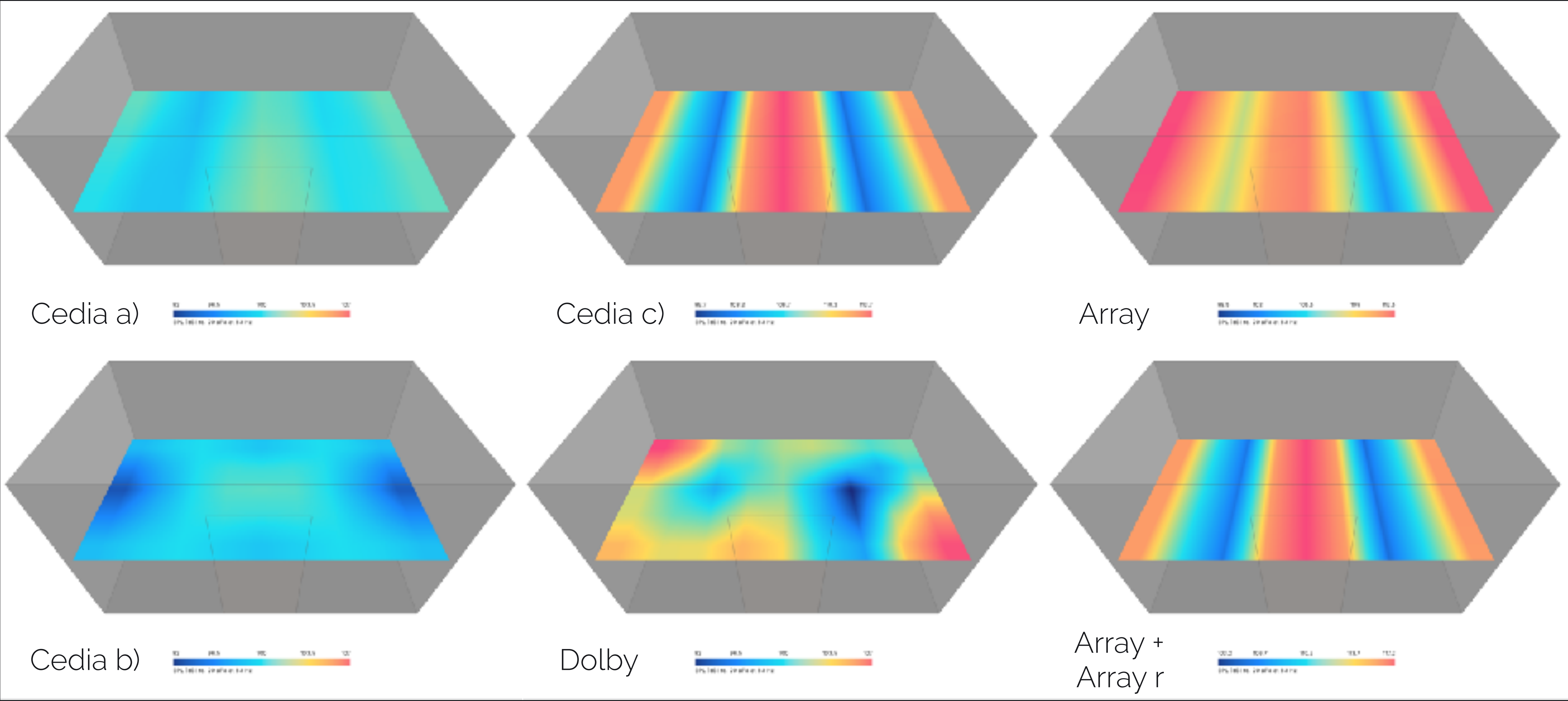
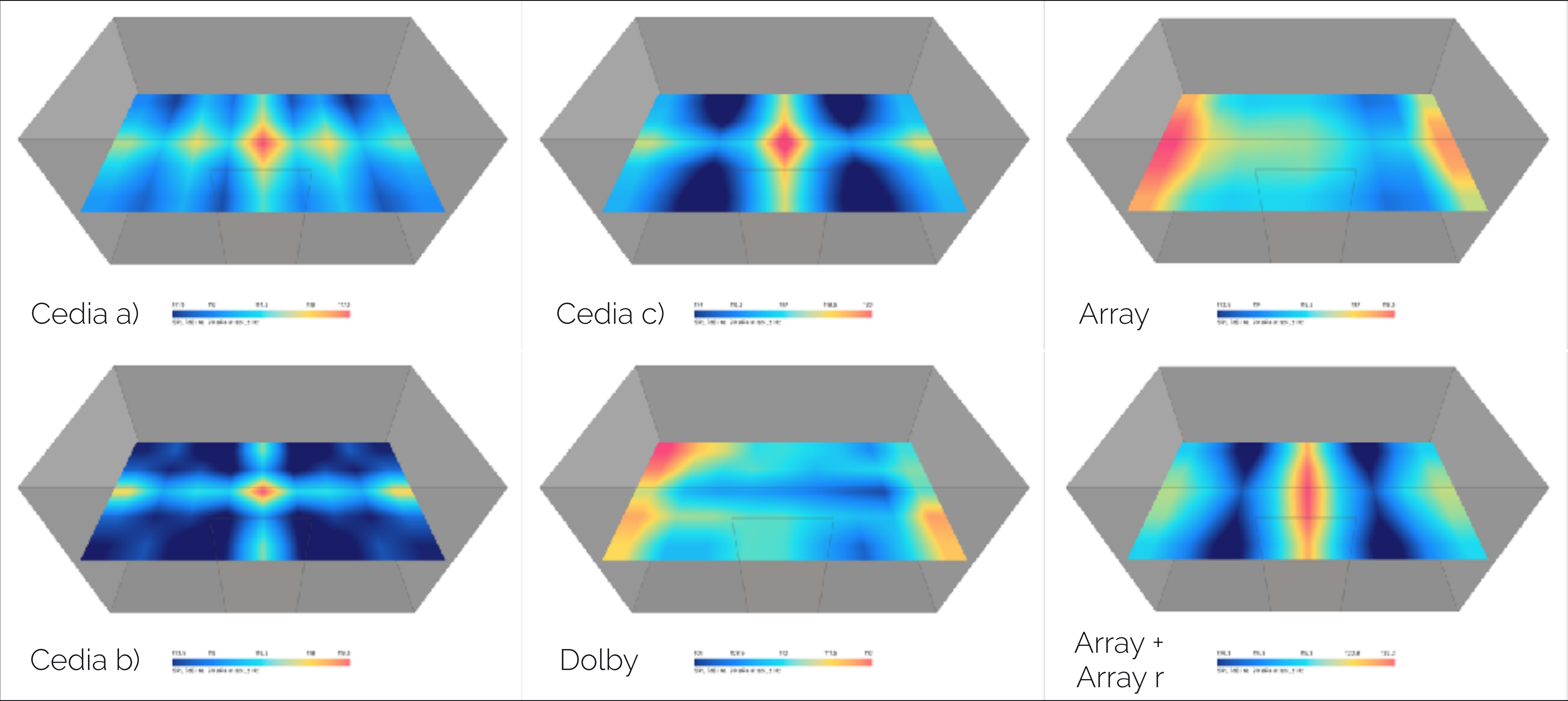
63 Hz



Total Z



Two Calibration Approaches for Low-Frequency Room Simulation

2024-2025 COMSOL
Physics-based impedance input

- Acoustic impedance derived from in-situ measurements
- MT60 analysis following Magalotti-Cardinali methodology
- Complex, time-intensive procedure requiring specialized expertise
- Optimization routines available

2025-2026 Treble
Empirical RT matching

- Model calibrated by comparing measured vs. simulated reverberation times
- Octave-band alpha coefficients adjusted iteratively
- Internal algorithm converts alpha to complex impedance
- Faster workflow, no optimization yet

Result: Both approaches achieve consistent calibration validated against point frequency response measurements

Observations & Limitations

What works:

- Both methods produce reliable predictions across the frequency range
- Frequency response validation confirms model accuracy

Where challenges remain:

- Discrepancies increase near material resonance frequencies *(e.g., plasterboard)*
- Octave-band calibration resolution may miss narrowband phenomena
- Finer tuning (1/3 octave RT matching) would likely improve accuracy

Key trade-off:

- **COMSOL offers optimization capability but is an R&D tool, not practical for typical design projects**
- **TREBLE is designer-friendly and project-ready but currently lacks optimization**

The Path Forward

Low-frequency prediction in small-medium rooms is moving from theory to practice.
What's still missing:

1. Reliable acoustic impedance libraries for common construction materials
2. Refined methods for indirect impedance estimation – improved algorithms or simplified measurement protocols
3. Systematic validation case studies – documented comparisons between simulation and measurement

The tools are becoming accessible.
The data infrastructure needs to catch up.

BAAM!

Boundary Admittance Measurement Method (BAMM!)

Peter D'Antonio*[2], Michael Vorlaender[1], Markus Mueller-Trapet[3]

[1]IHTA, RWTH Aachen University, Aachen, Germany;
[2]REDI Acoustics, Highland, New York, United States;
[3]National Research Council Canada, Ottawa, Ontario

We were fortunate to have several leading international acousticians in attendance:

- Trevor Cox, Keith Attenborough, Christian Nocke, Ning Xiang, Michael Vorlaender, Finnur Pind, Toru Otsuru, Peter D’Antonio

- We discussed forming three linked WGs TC AA of ASA, TC RBA of EAA and ASJ (Japan).
WG chairs to be determined.

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Thank You!

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