Modeling and Auralization:

Past and Progress

Kurt Graffy

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But first, a bit of history, from 27 years ago:

6th AES Conference on Sound Reinforcement
Nashville, Tennessee May 1988

And the software buzz then was:

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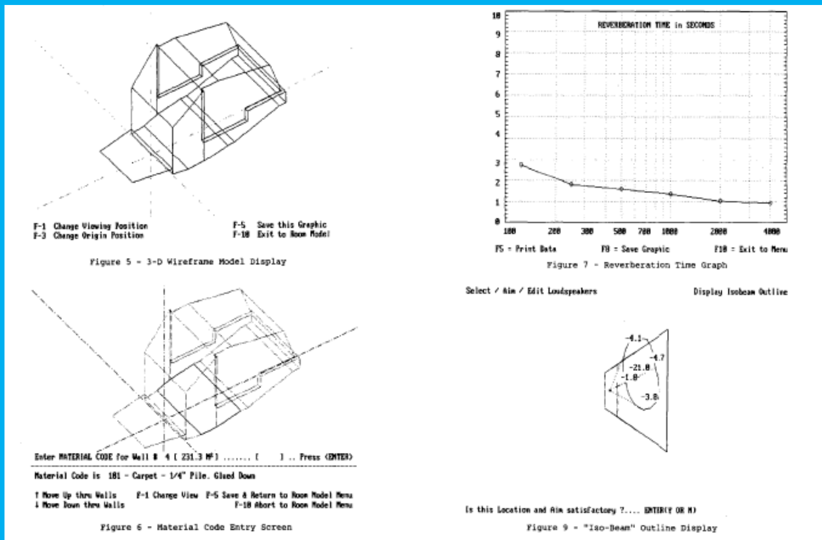
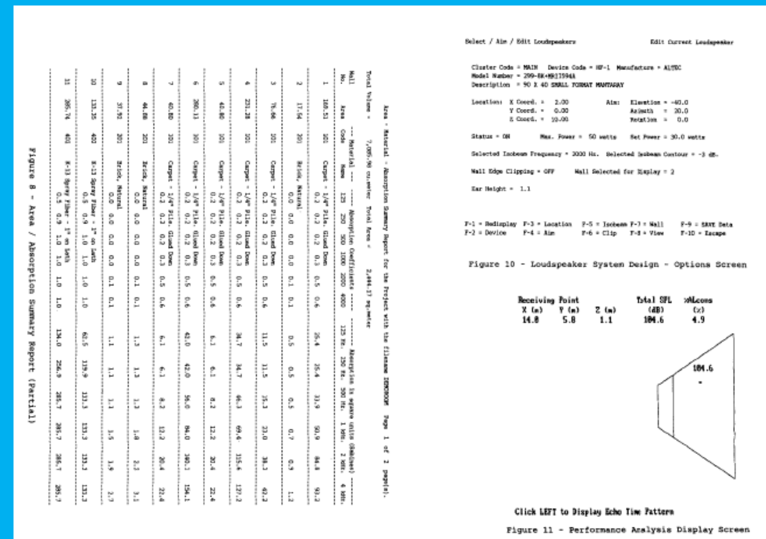
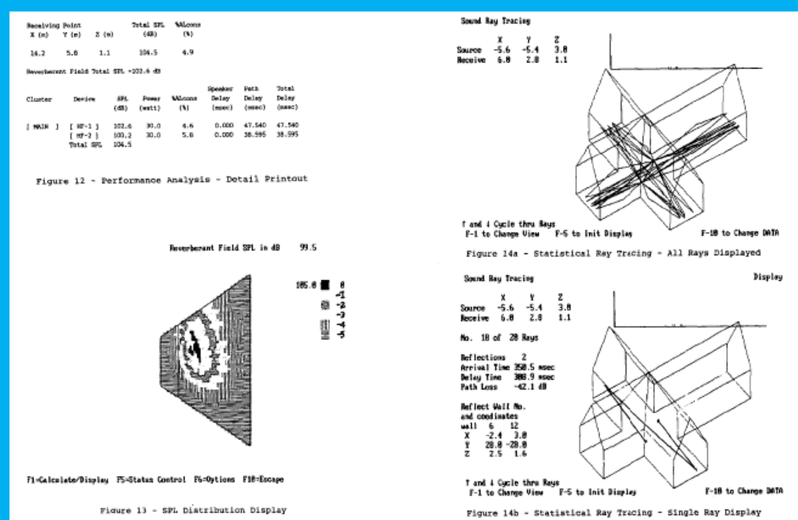
6th AES Conference on Sound Reinforcement Nashville, Tennessee May 1988







Altec AcoustaCADD

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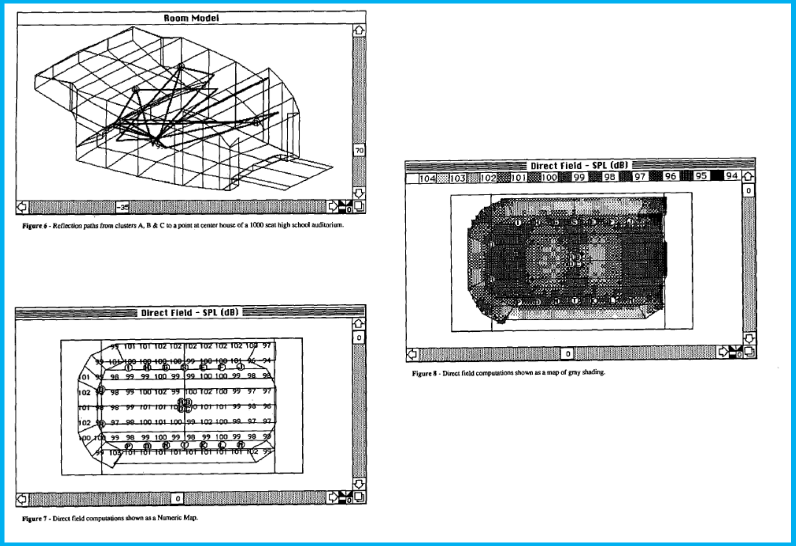
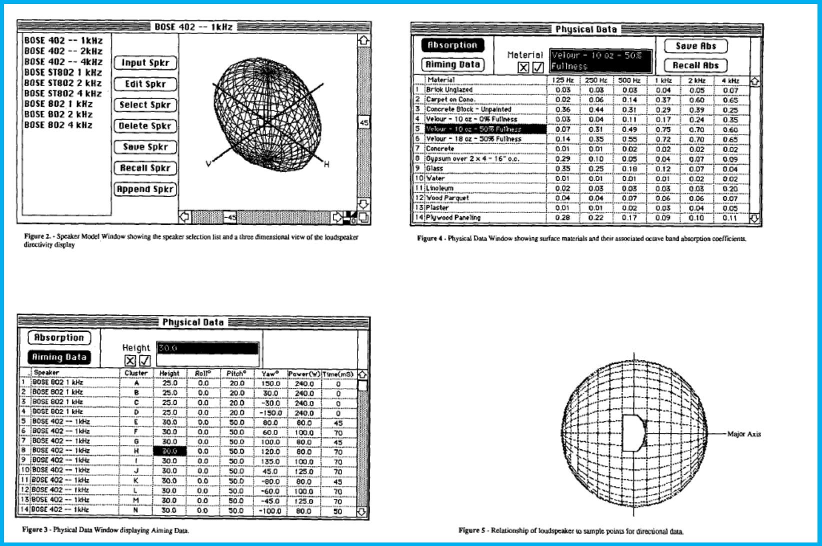
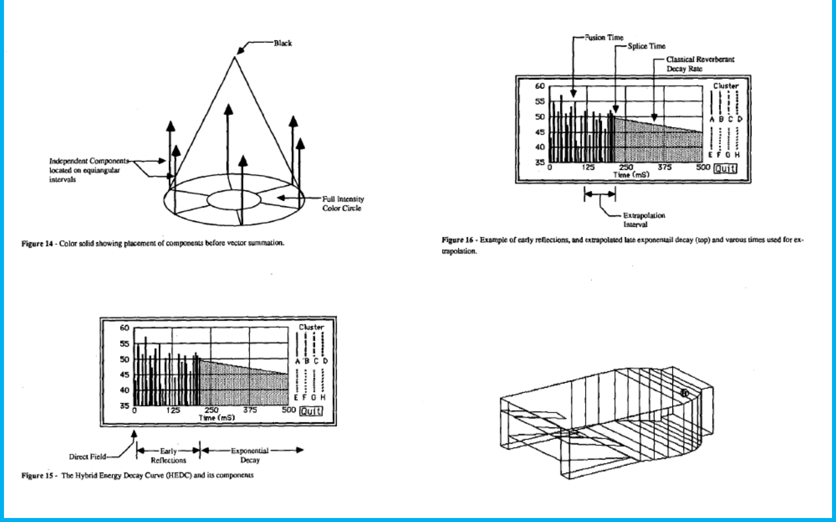
6th AES Conference on Sound Reinforcement
Nashville, Tennessee May 1988

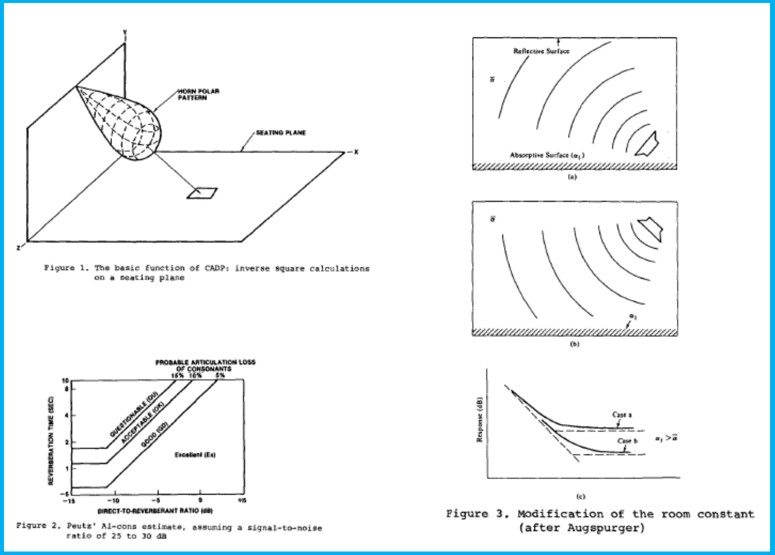


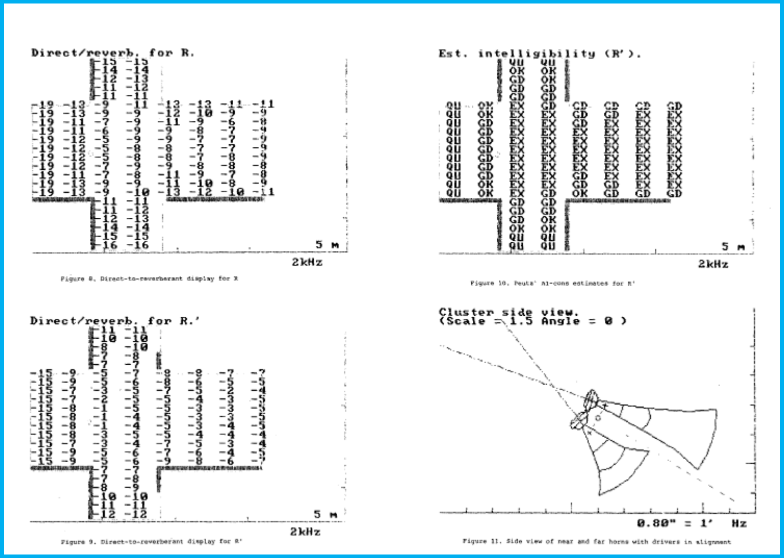


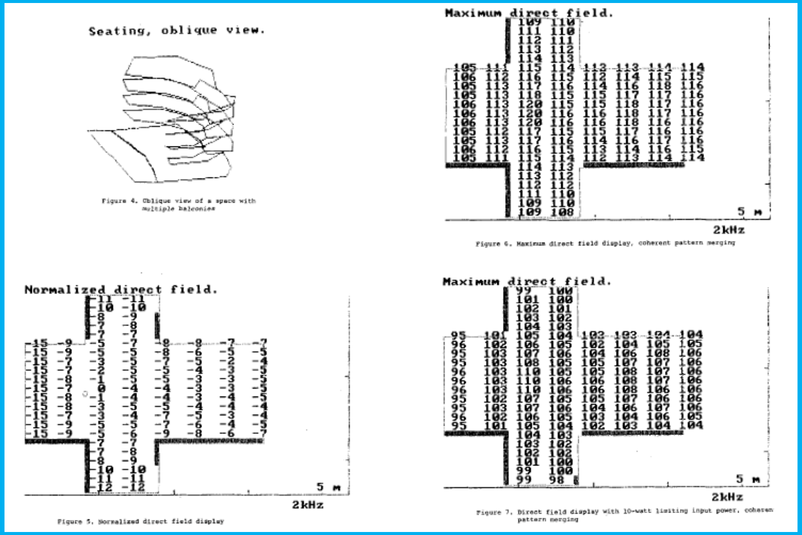


BOSE Modeler

6th AES Conference on Sound Reinforcement
Nashville, Tennessee May 1988







JBL
CADP

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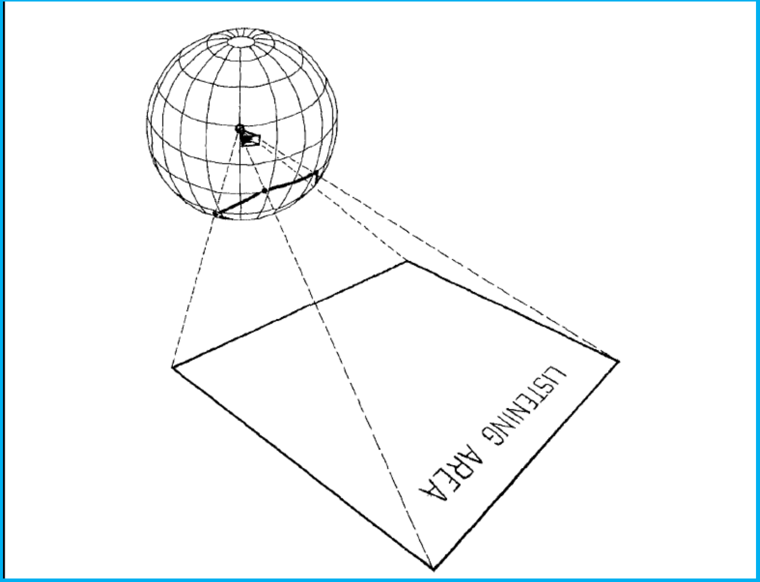
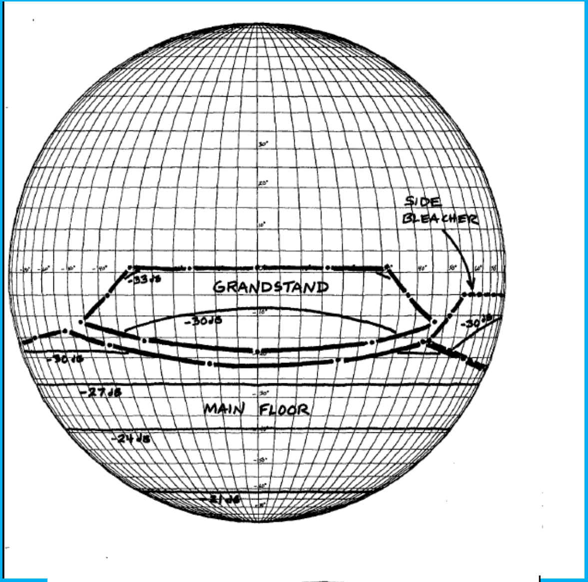
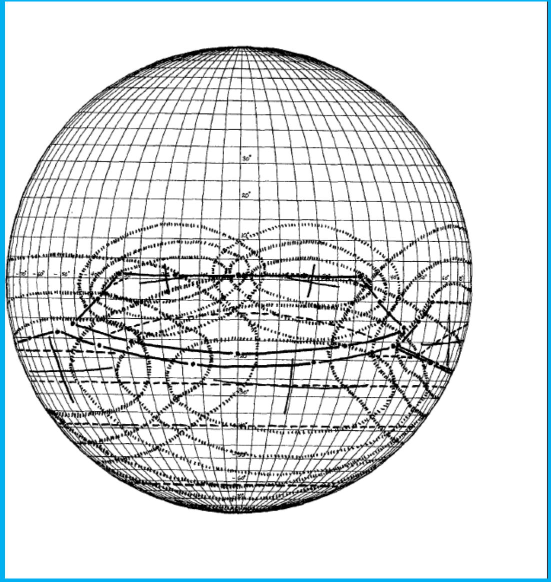
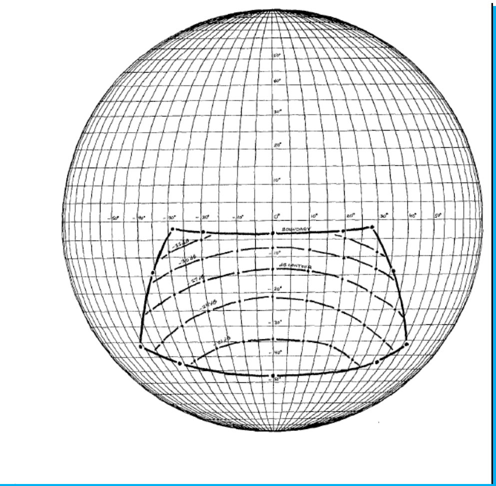
Not at the 6th AES Conference on Sound Reinforcement Nashville, Tennessee May 1988









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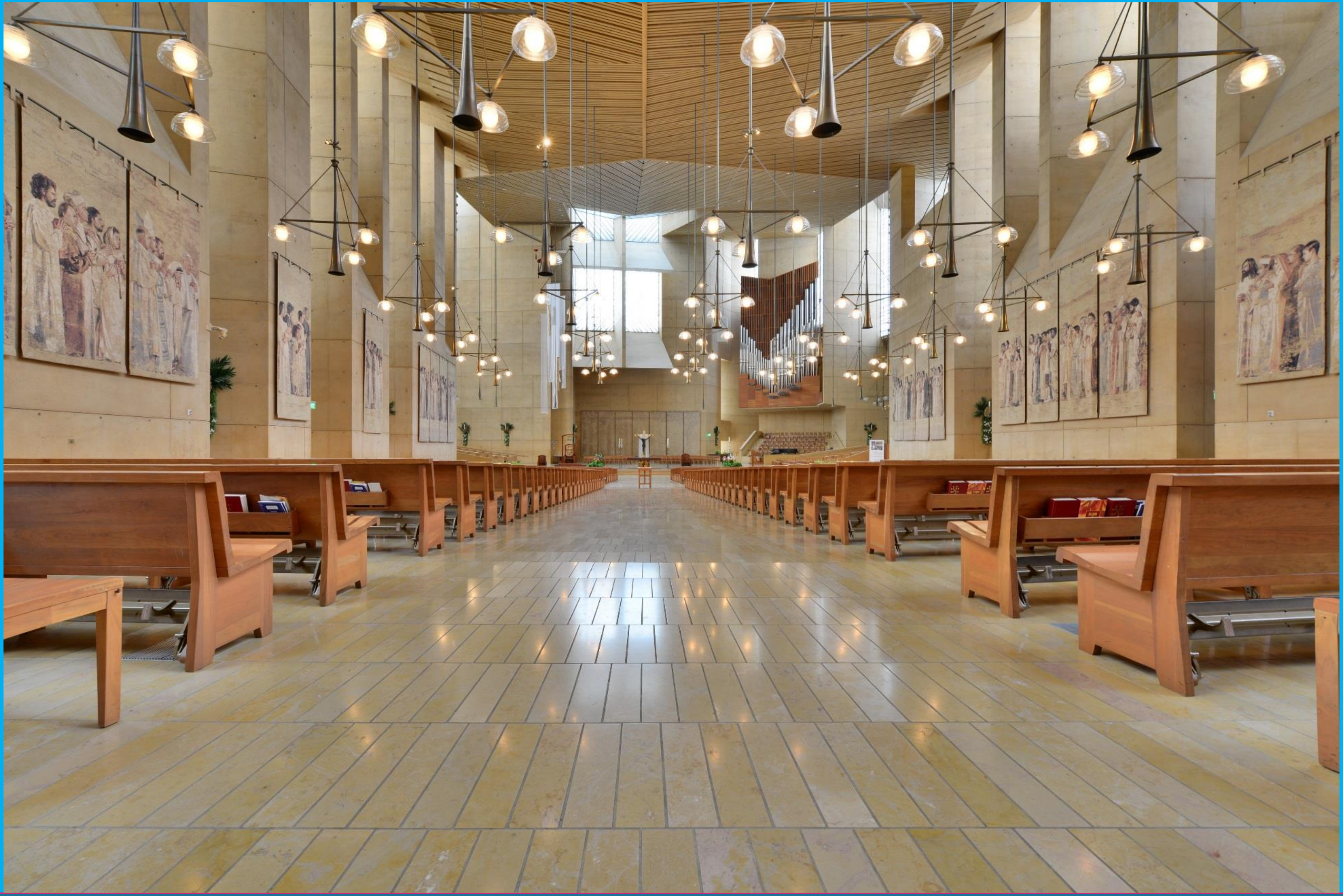
A mere 10 years later....

Here's what was going on...

Auralization for new LA Cathedral:

Cathedral of Our Lady Of Angels, Los Angeles - 1998



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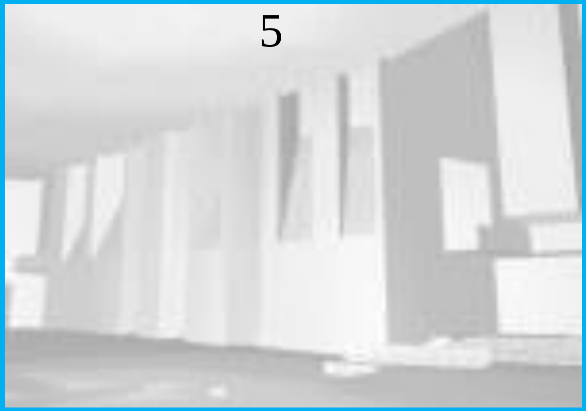
Cathedral of Our Lady Of Angels, Los Angeles - 1998

View from Front of Nave

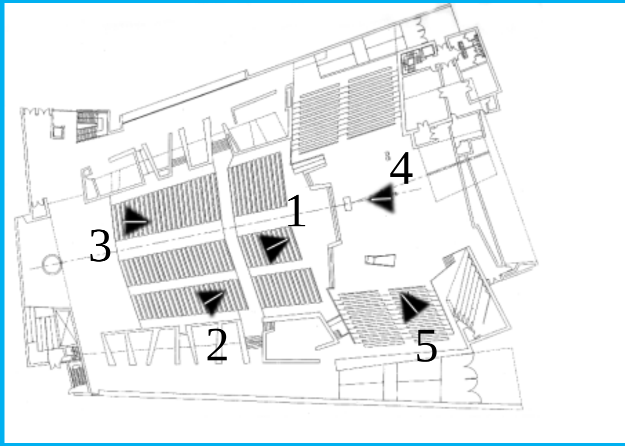
View from Mid-Nave

View from Rear of Nave

View from Chancel



View from Transept (choir)



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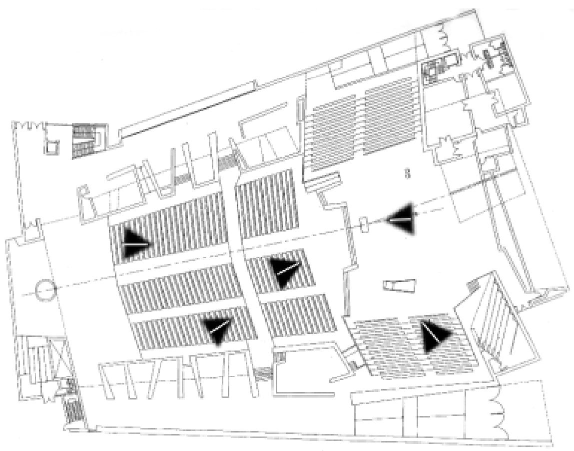
Cathedral of Our Lady Of Angels, Los Angeles - 1998

The Cathedral of Our Lady of the Angels



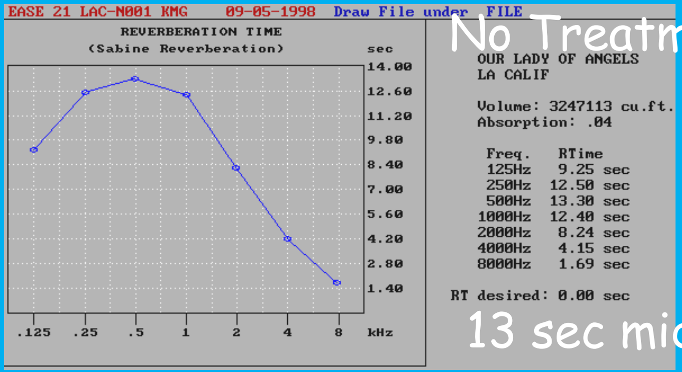
The next step in the process is to select a sound source and then one of the listening positions. The floorplan above shows the listening locations and the arrows show the direction that the listener is facing. As you place your mouse over the listening positions below the image above will change to show you the view from those positions.

Unaided Talker	Pewback System	Split Clusters
Chancel	Chancel	Chancel
Transept	Transept	Transept
Nave Front	Nave Front	Nave Front
Nave Middle	Nave Middle	Nave Middle
Nave Rear	Nave Rear	Nave Rear

About the Recommended Room Acoustics

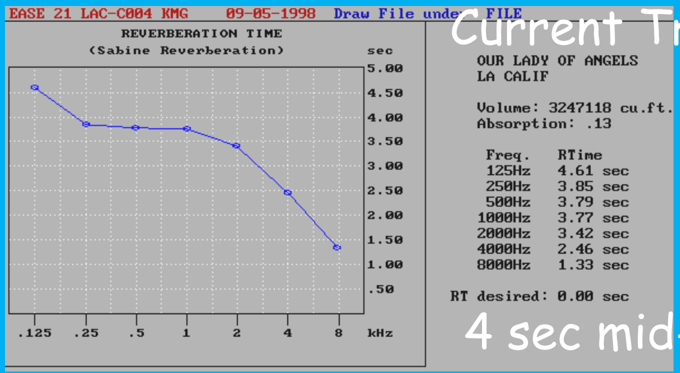
Volume is 3,247,000 cubic feet
or 1,080 cubic feet per seat

No Treatment



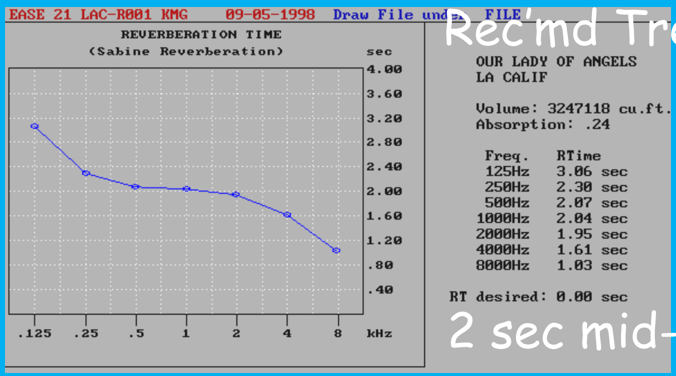
13 sec mid-band

Current Treatment



4 sec mid-band

Rec'md Treatment



2 sec mid-band

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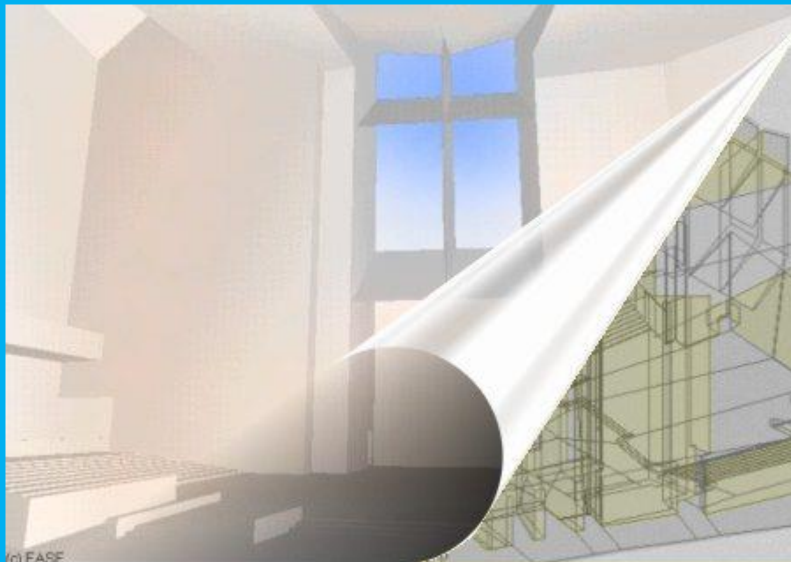
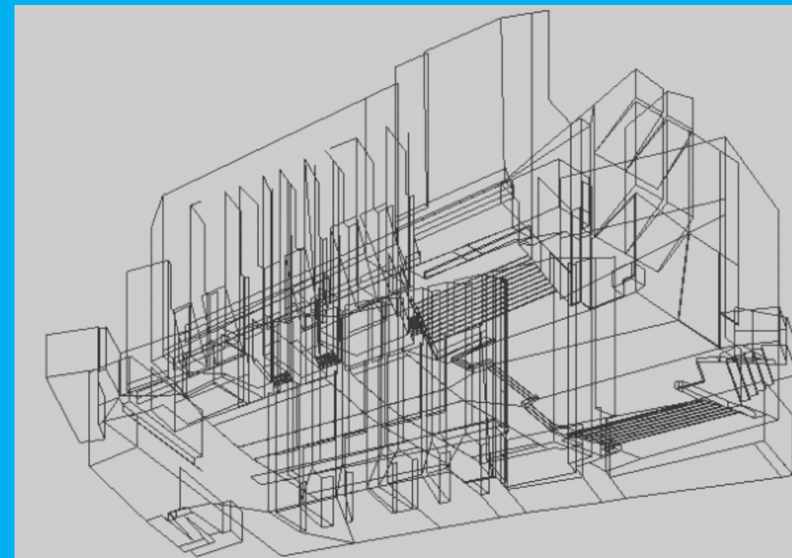
Cathedral of Our Lady Of Angels, Los Angeles





What we had to do to create the IR for Auralization:
Computer Farm!
(5) Computers @300 MHz
1 computer per listener location
Computers were on UPS, running 24/7 for 5 weeks to generate impulse responses

1998 Our Lady Of Angels Cathedral Los Angeles

Preparation:

Room model “built” and “skinned”.
Impulse Reponse generated for:
Five Listener Locations
Each listener location was modeled with 3 different sources
Human talker, Distributed Arrays, Pewback system
Each listener location modeled with 3 different acoustical conditions
No Treatment, Current Treatment, Recommended Treatment

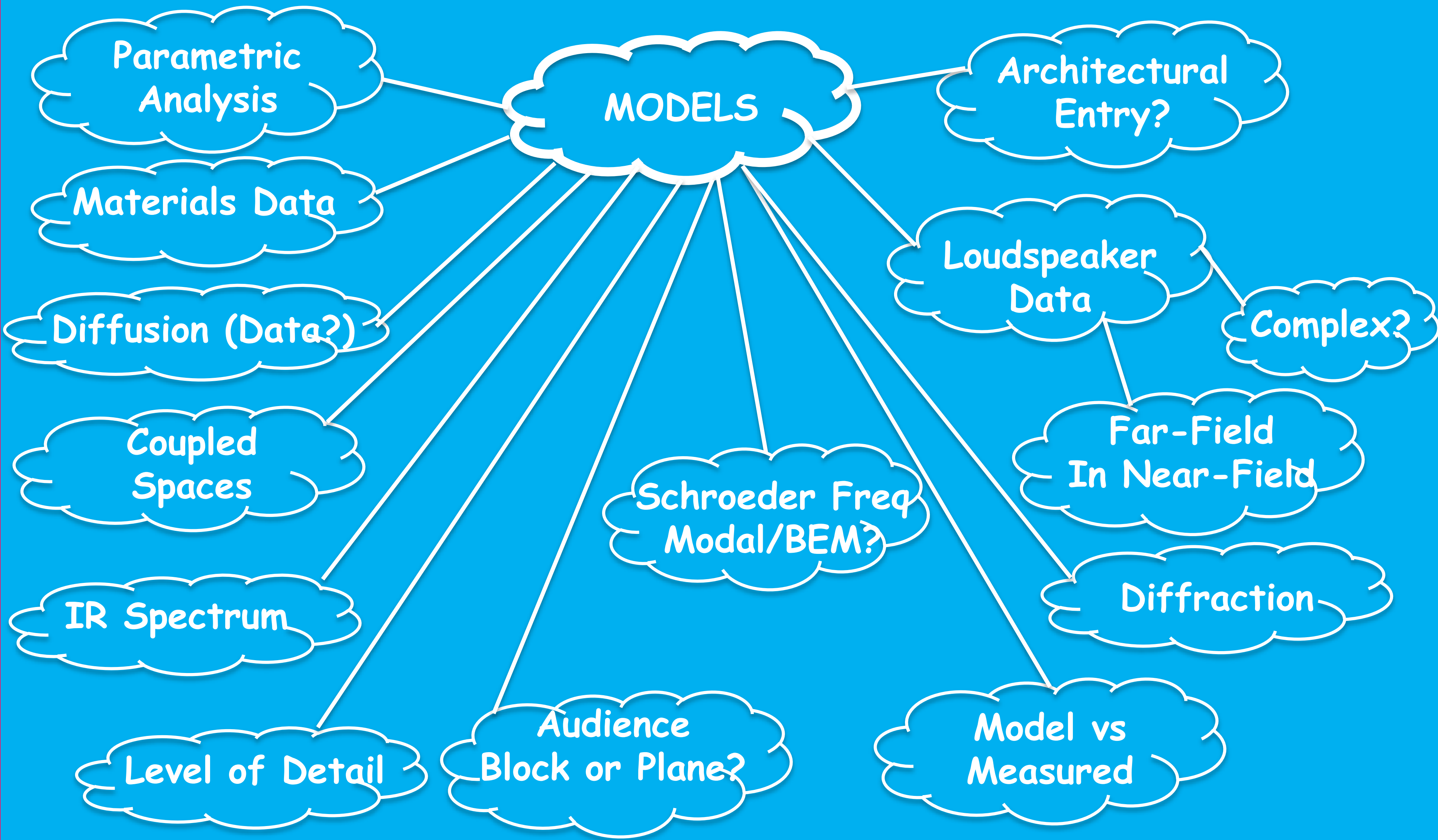
Presentation to the Cardinal and Architect:

Impulse Reponse fed Lake Huron Convolver BUT
Huron did not have enough taps for the length of the IR!
Consequently Convolved IR was fed through Lexicon 480 to
develop the reverberant tail necessary for the decay time.
Convolution was “live” via a live talker (KMG) on wireless microphone
Listeners heard “real-time” binaural auralizations via IR wireless headphones
No acoustic “time zero” so latency effects negated.

So just Build 'em, what Could Be Simpler?

MODELS

Perhaps just a few things…



5 Key Things to Consider

1. Level of Detail to Use
2. Application / Approach to Diffusion/Diffraction
3. How to handle frequencies below 125 Hz (below Schroeder)
4. Mapping Patch Size, Length of Echogram re Room
5. Note: GA Prediction methods are best suited to investigate main impacts of room size and shape…and distribution of absorbing and diffusing surfaces.
6. And oh yeah….Level of Detail to Use

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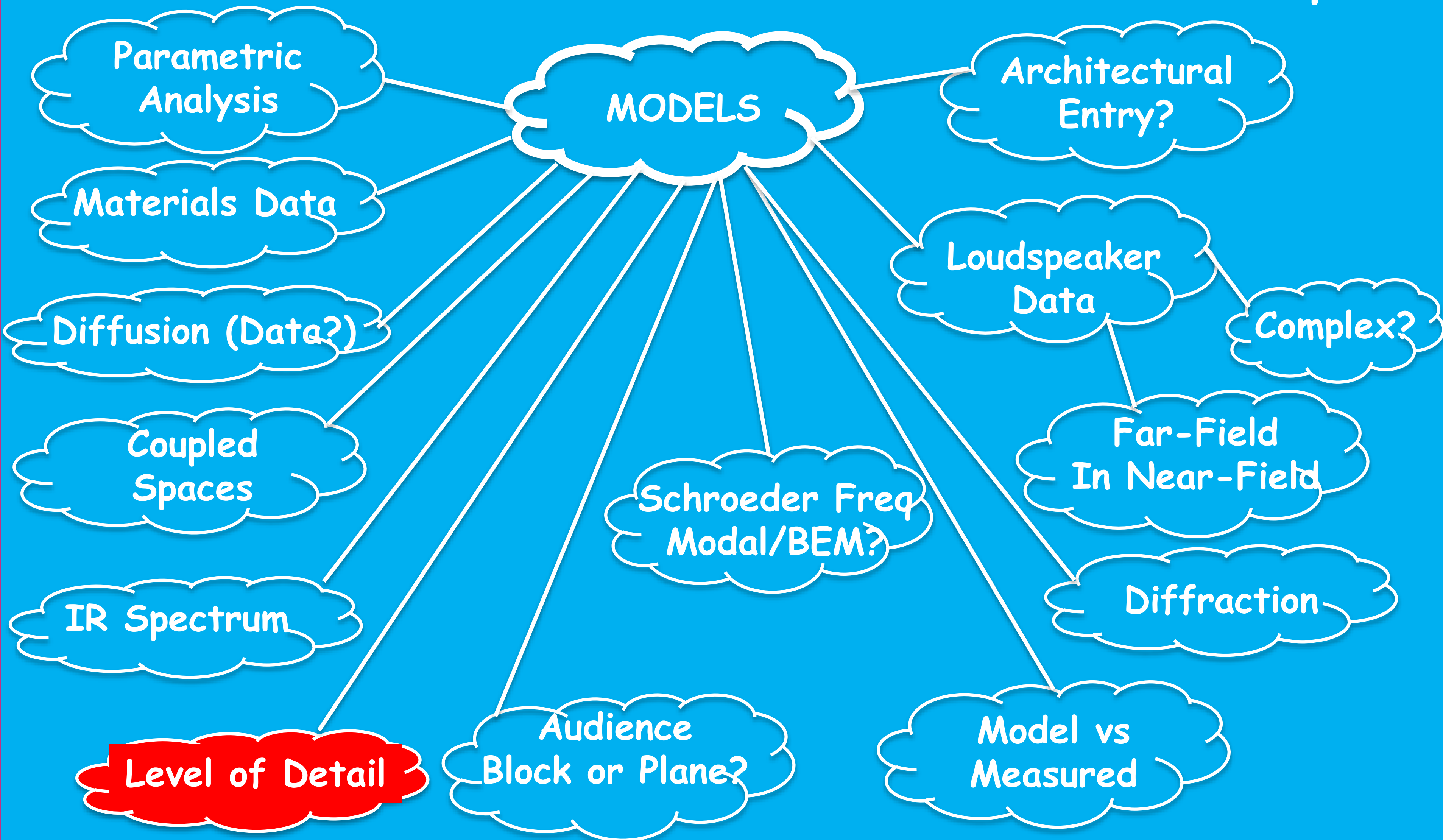
Models – Just Build 'em, what Could Be Simpler?



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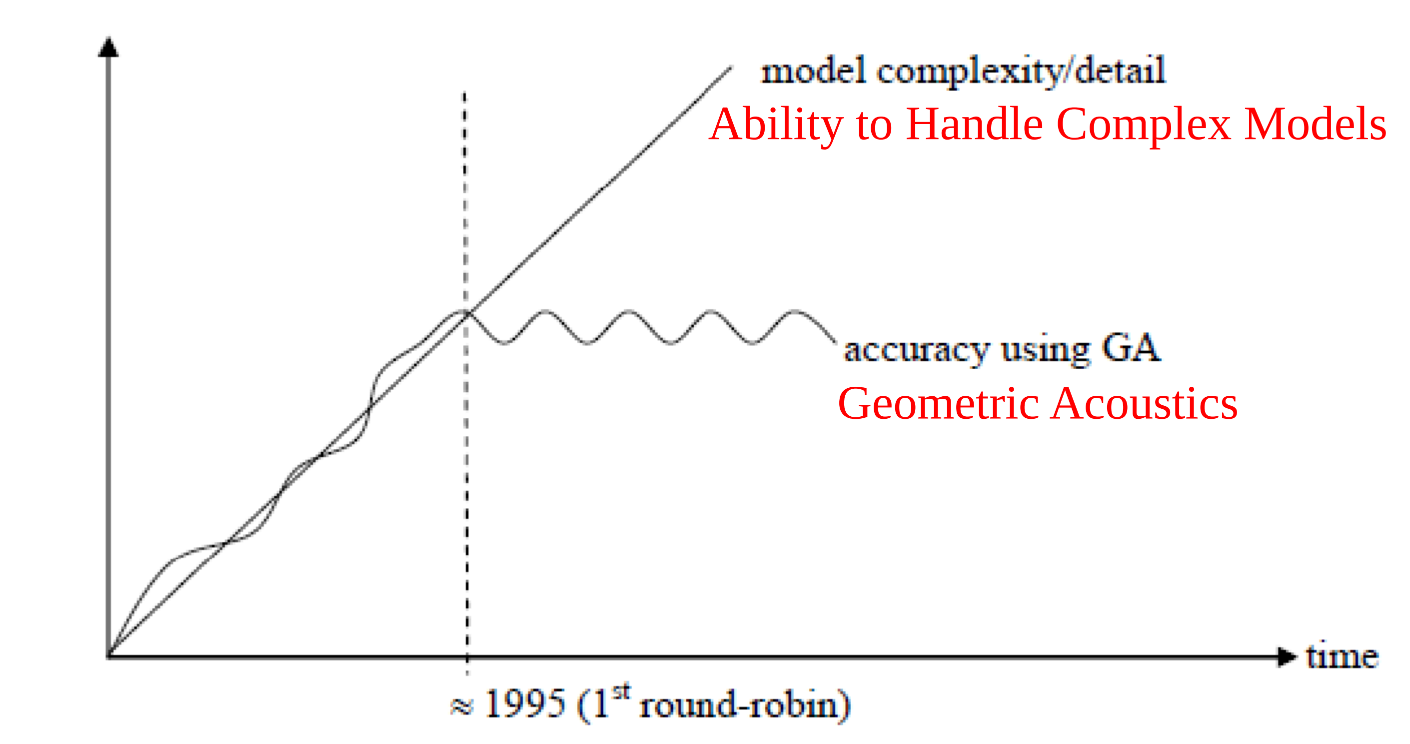
Modeling – What Level of Detail?



Schematic Curve of:
Model Complexity vs Geometric Acoustic Accuracy

"Engineering Principles and Techniques in Room Acoustic Prediction", Dahlenback_BNAM 2010

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Modeling – Detail and Realization

One can consider Geometric Acoustics (GA) Applicable if:

- The wavelength λ is much smaller than smallest dimension of the surface (d)
  - Such that $\lambda \ll d$
- In practice this expanded to be simply $\lambda < d$
- But…what's crept in now are claims like:
  - Detailed geometry is relevant, and will provide diffusion
  - LF where $\lambda \gg d$ can be modeled with GA

"Engineering Principles and Techniques in Room Acoustic Prediction", Dahlenback_BNAM 2010

Modeling – Detail and Realization

So. Let's Consider theTwo Claims regarding Detail and Diffusion:

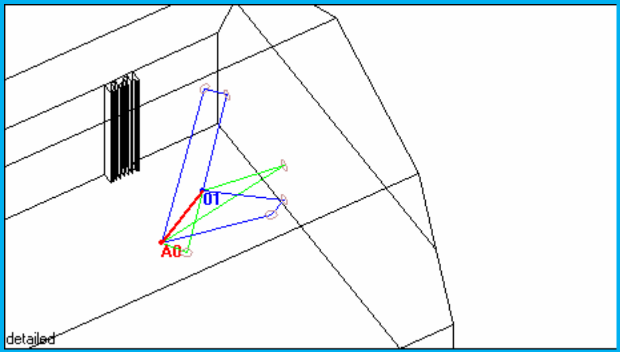
- With sufficient modeling of detail the diffusing effect of surfaces can be generated,
  versus
- Use Frequency Dependent Scattering (FDS) coefficients on flat surface and omit the details

How does that work out?…how does it compare to a measured "real-world" situation?

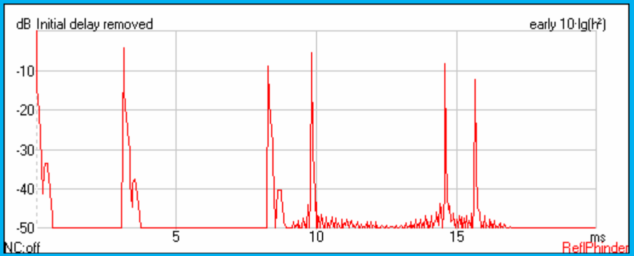
"Engineering Principles and Techniques in Room Acoustic Prediction", Dahlenback_BNAM 2010

Modeling – Detail and Realization

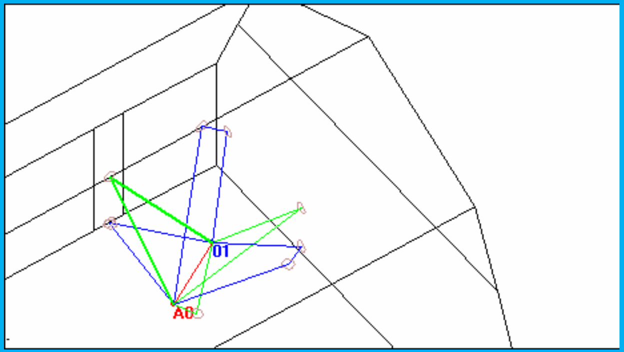
Consider Two Claims regarding Detail:

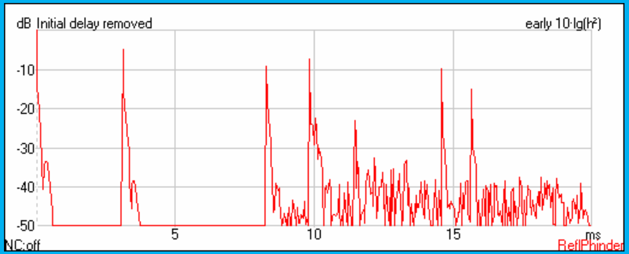


Highly Detailed
Will Geometry Work?



Nope

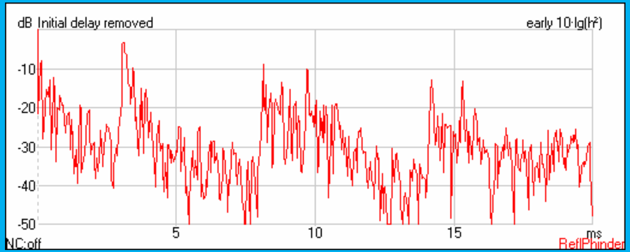




Planar surface + FDS
Direct plus diffuse tail

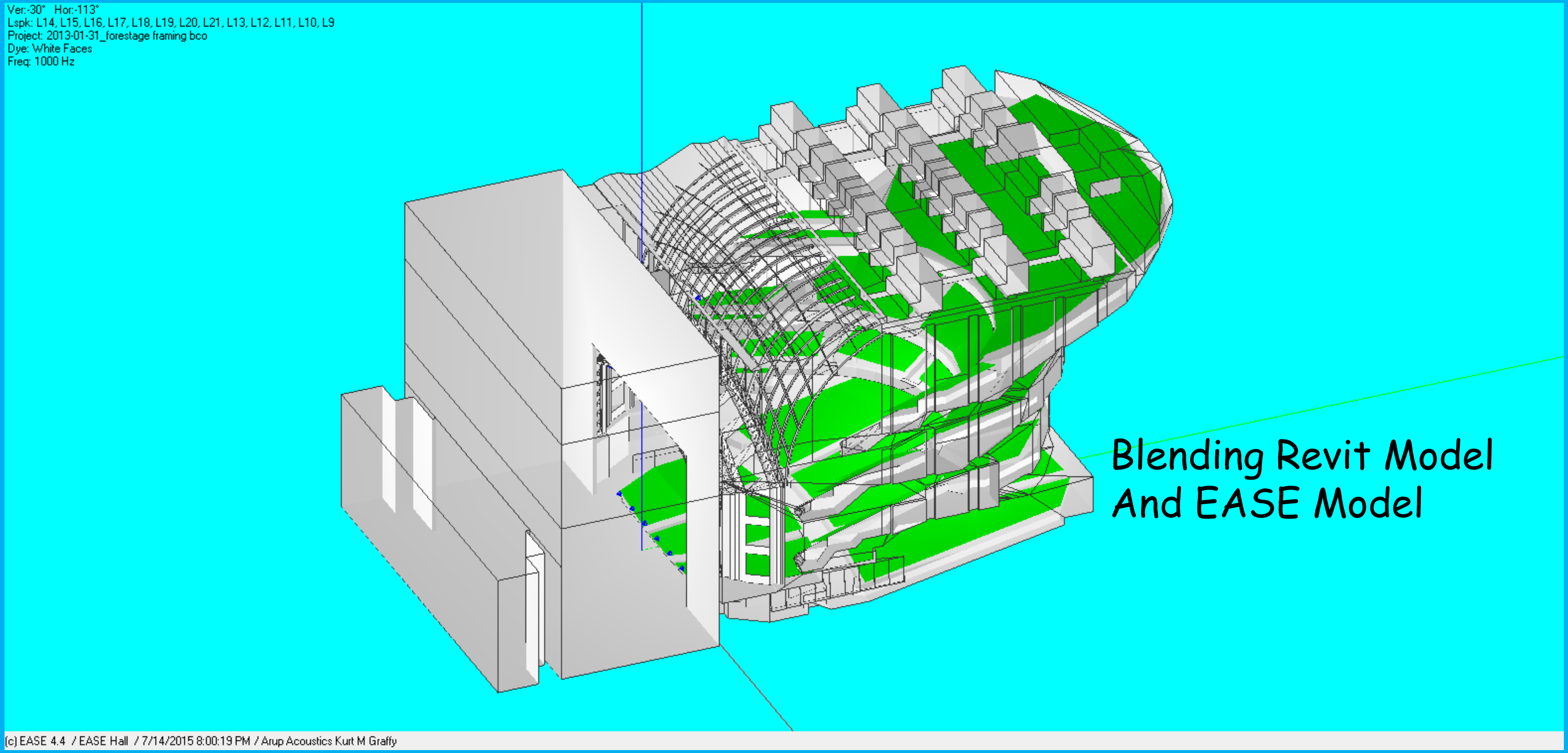
Yup…it's a better way to Go

Referenced Against Measured
Direct plus diffuse tail



"Engineering Principles and Techniques in Room Acoustic Prediction", Dahlenback_BNAM 2010

Modeling – Blended Models



Blending Revit Model
And EASE Model

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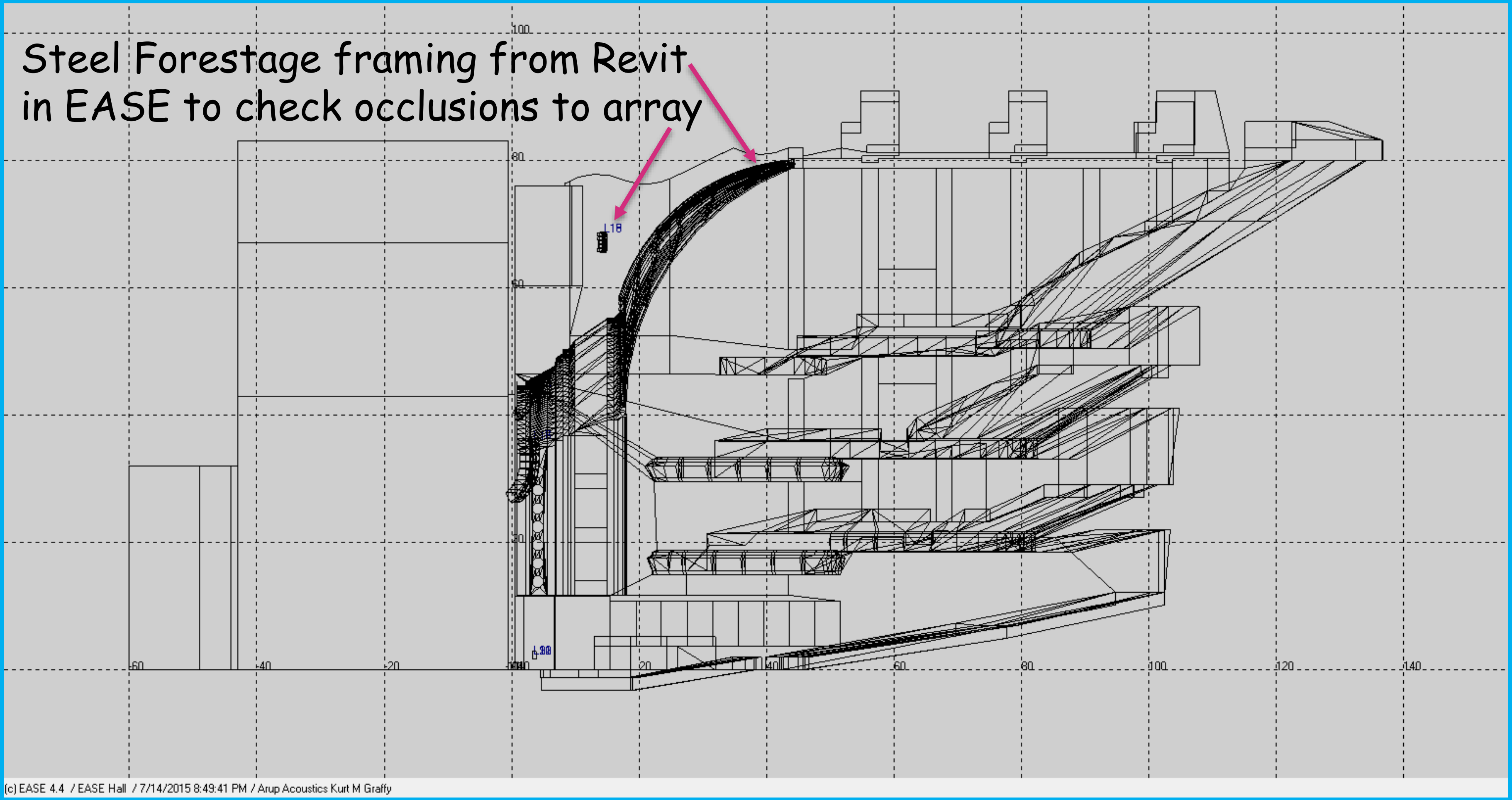
Modeling – Blended Models



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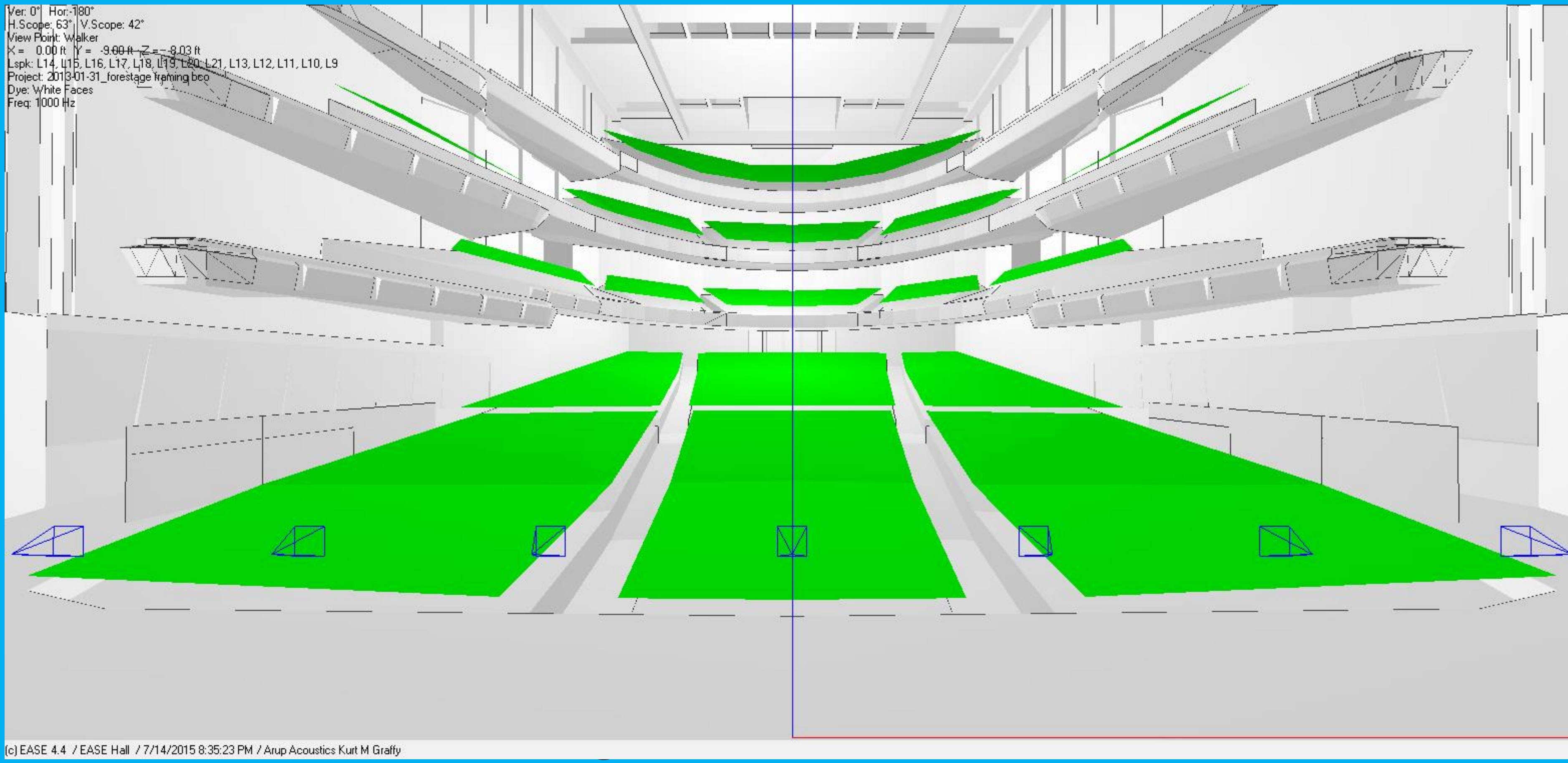
Modeling – Blended Models



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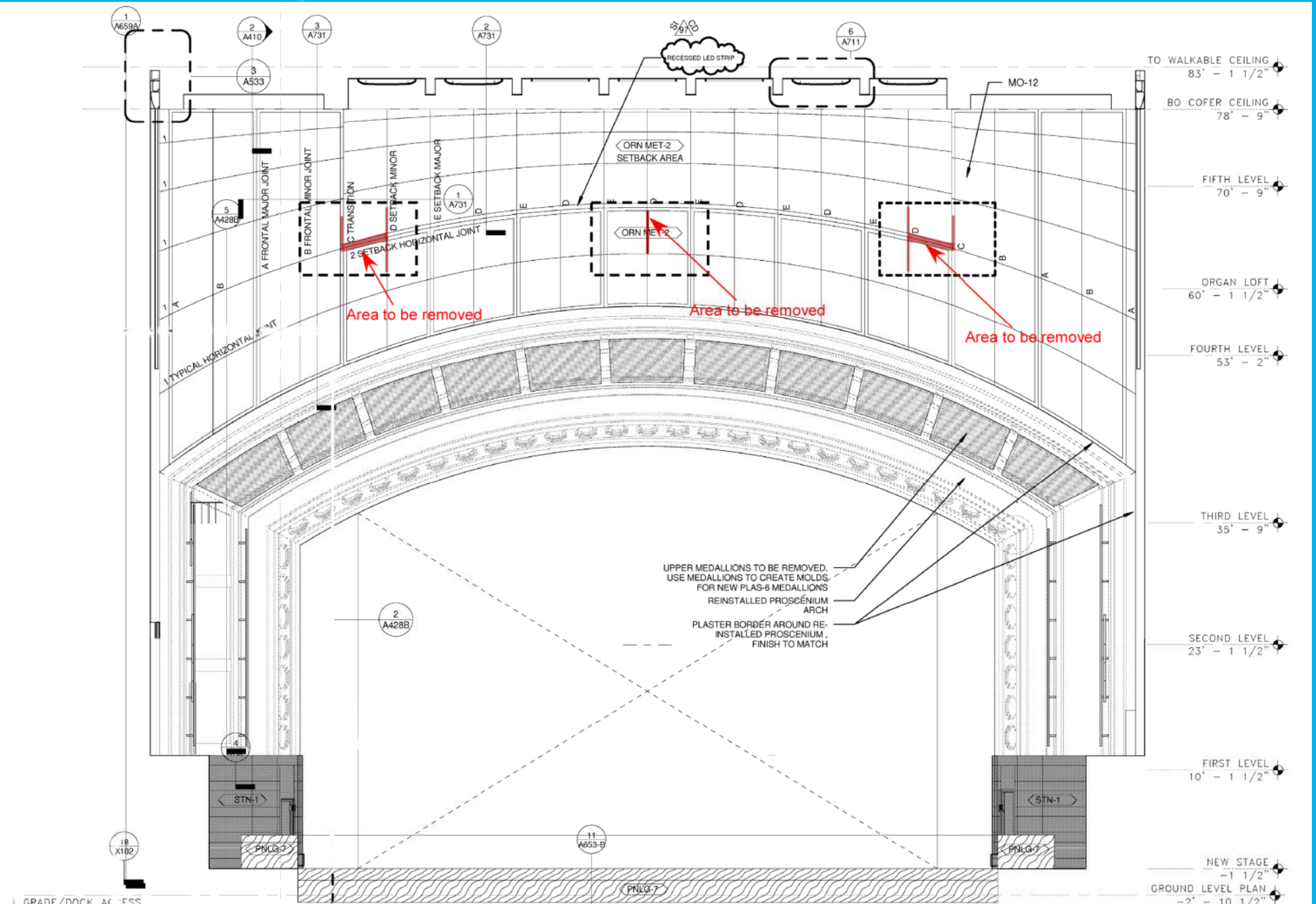

- **Occluding Elements to be Revised**

2 PERFORMANCE HALL NORTH ELEVATION
1/8" = 1'–0"

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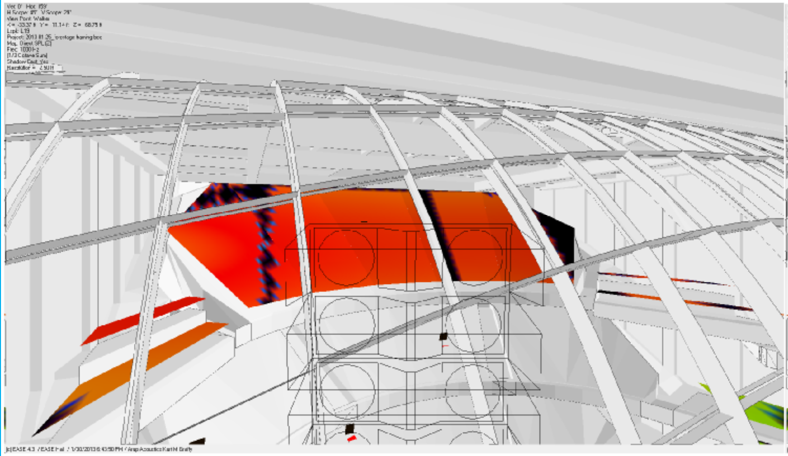
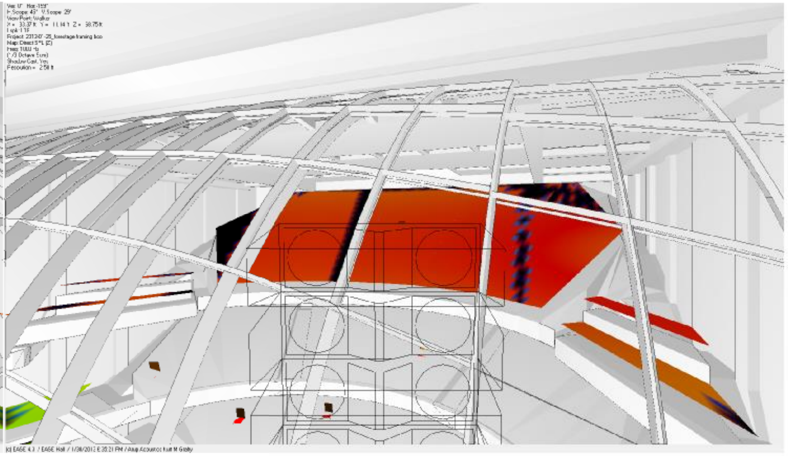
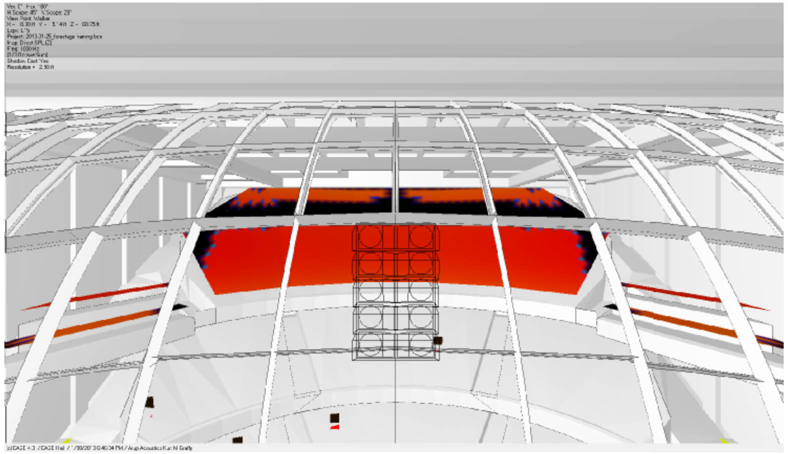
Modeling – Blended Models

STAGE LEFT ARRAY ONLY



STAGE RIGHT ARRAY ONLY





CENTER ARRAY ONLY

IMPACT OF FORESTAGE SCREEN FRAME ON 3RD BALCONY COVERAGE

ORIGINAL ARRAY LOCATIONS

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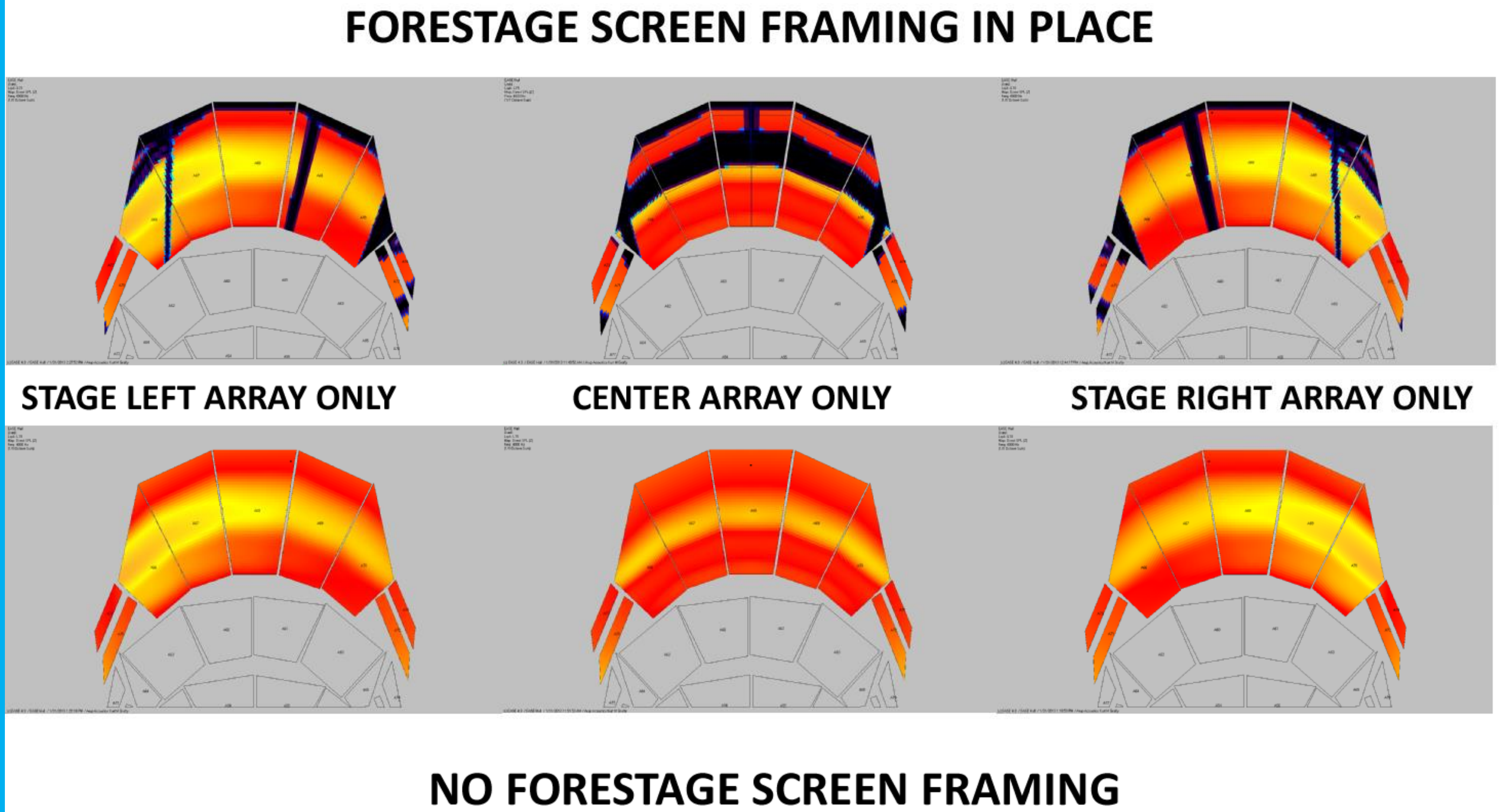
Modeling – Blended Models

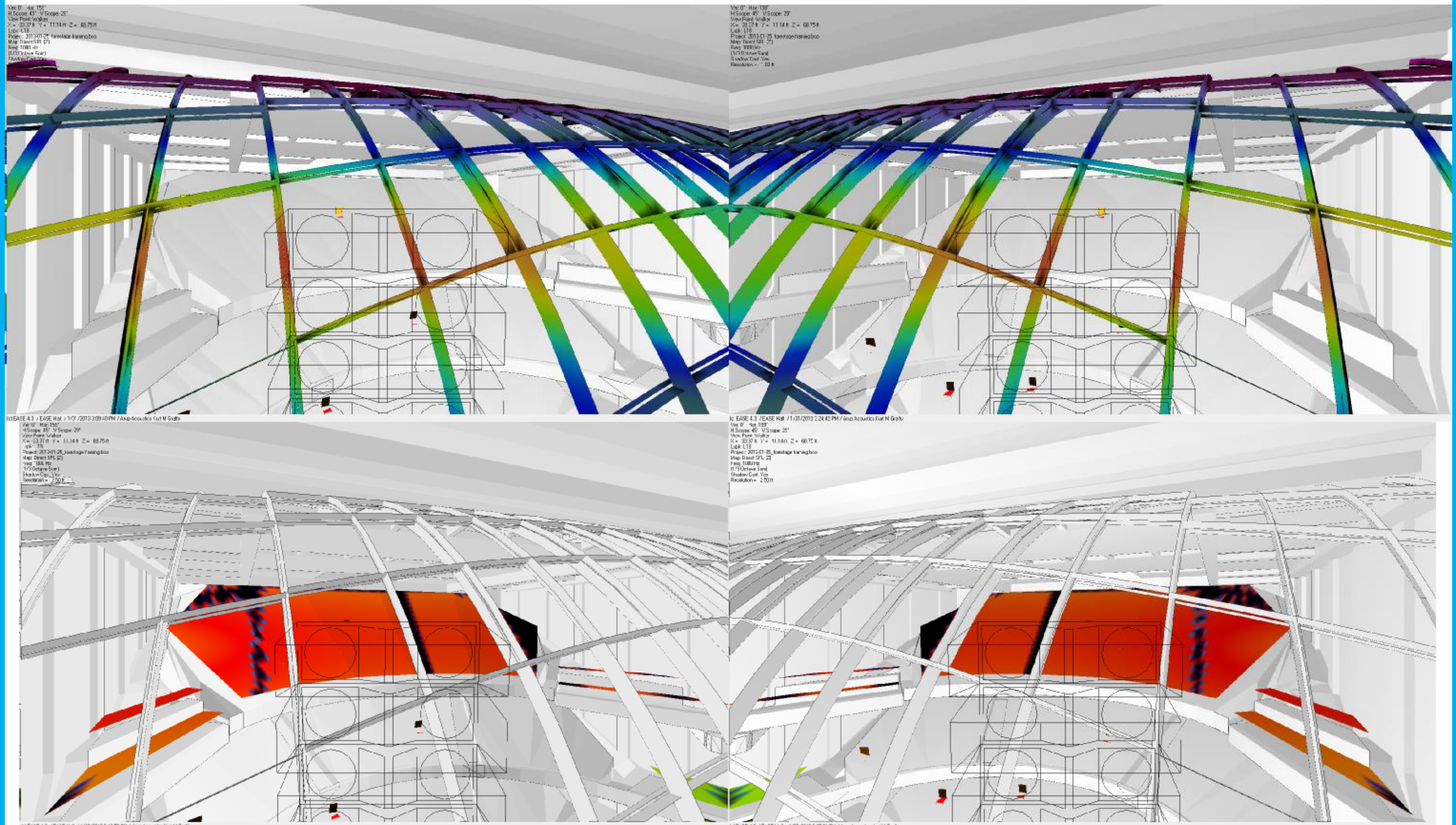


IMPACT OF FORESTAGE SCREEN FRAMING ON 3RD BALCONY COVERAGE

ORIGINAL ARRAY LOCATIONS

Modeling – Blended Models

MAPPING OF AUDIO INTENSITY ON FORESTAGE SCREEN FRAMING



STAGE LEFT ARRAY ONLY

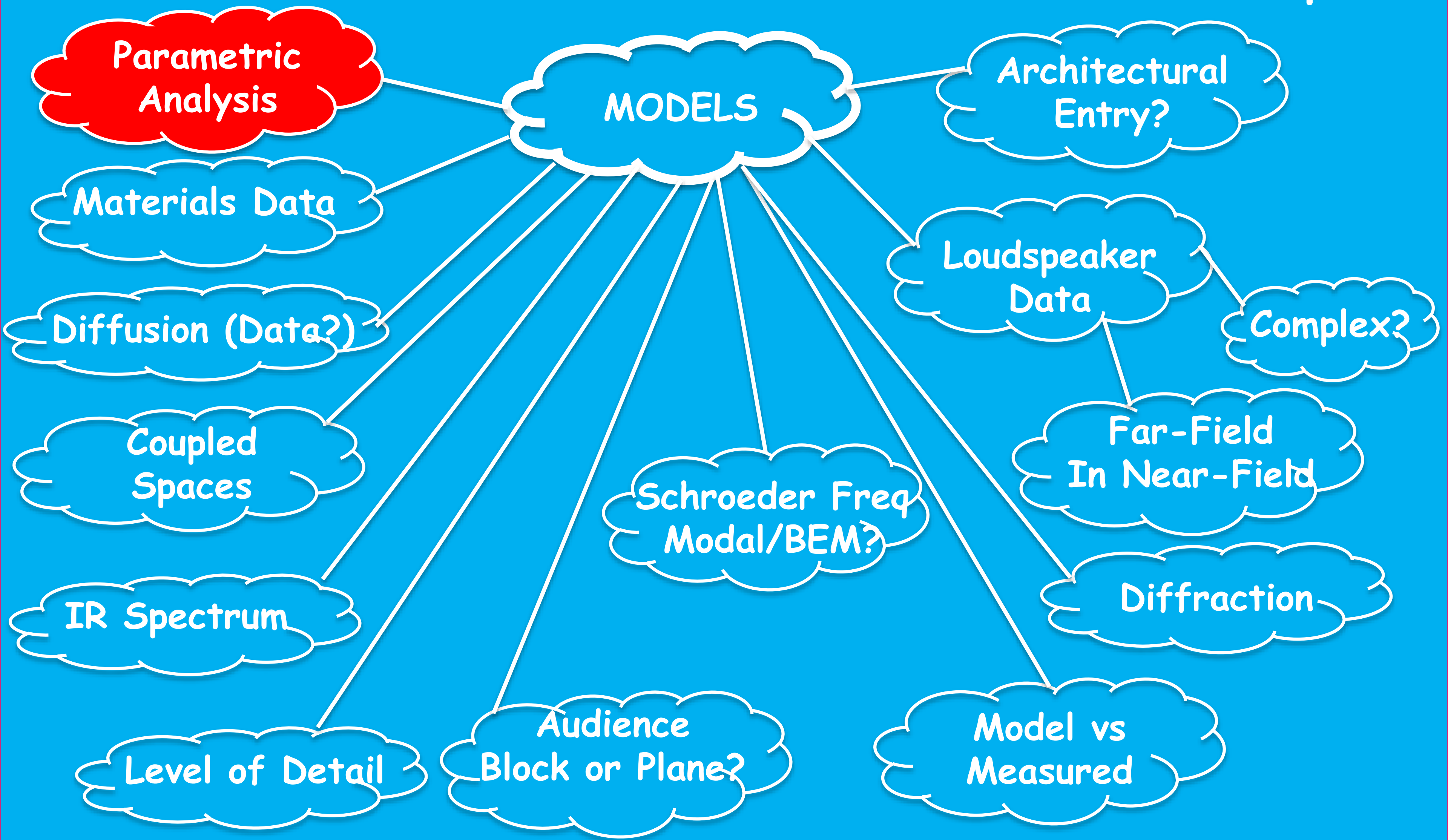
STAGE RIGHT ARRAY ONLY

BLACK AREAS ARE OCCLUDED BY FORESTAGE SCREEN FRAMING

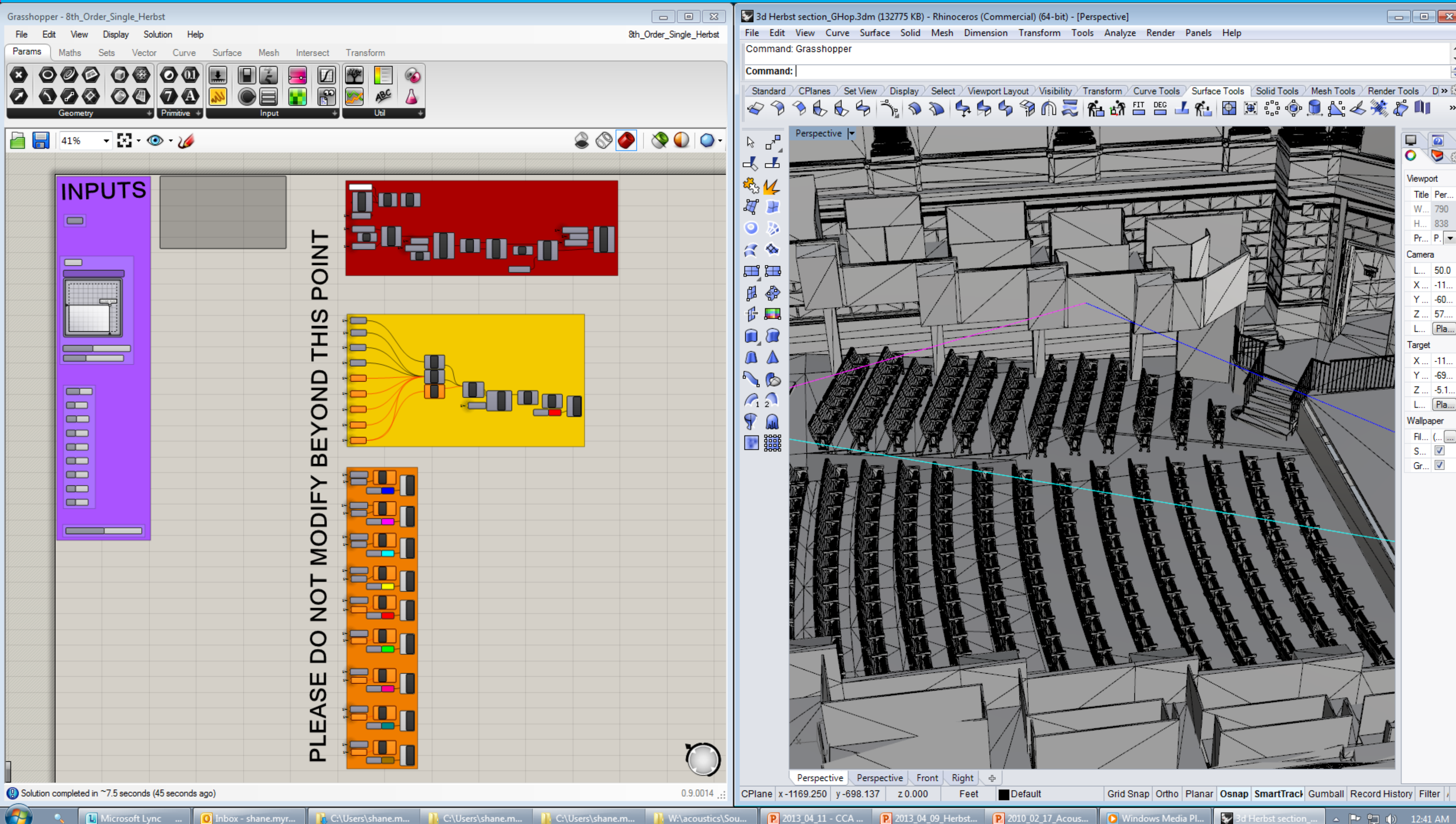
AREAS OF FORESTAGE SCREEN FRAMING OCCLUDING UPPER ARRAYS

ORIGINAL ARRAY LOCATIONS

Models – Just Build 'em, what Could Be Simpler?



Modeling - Parametric Analysis



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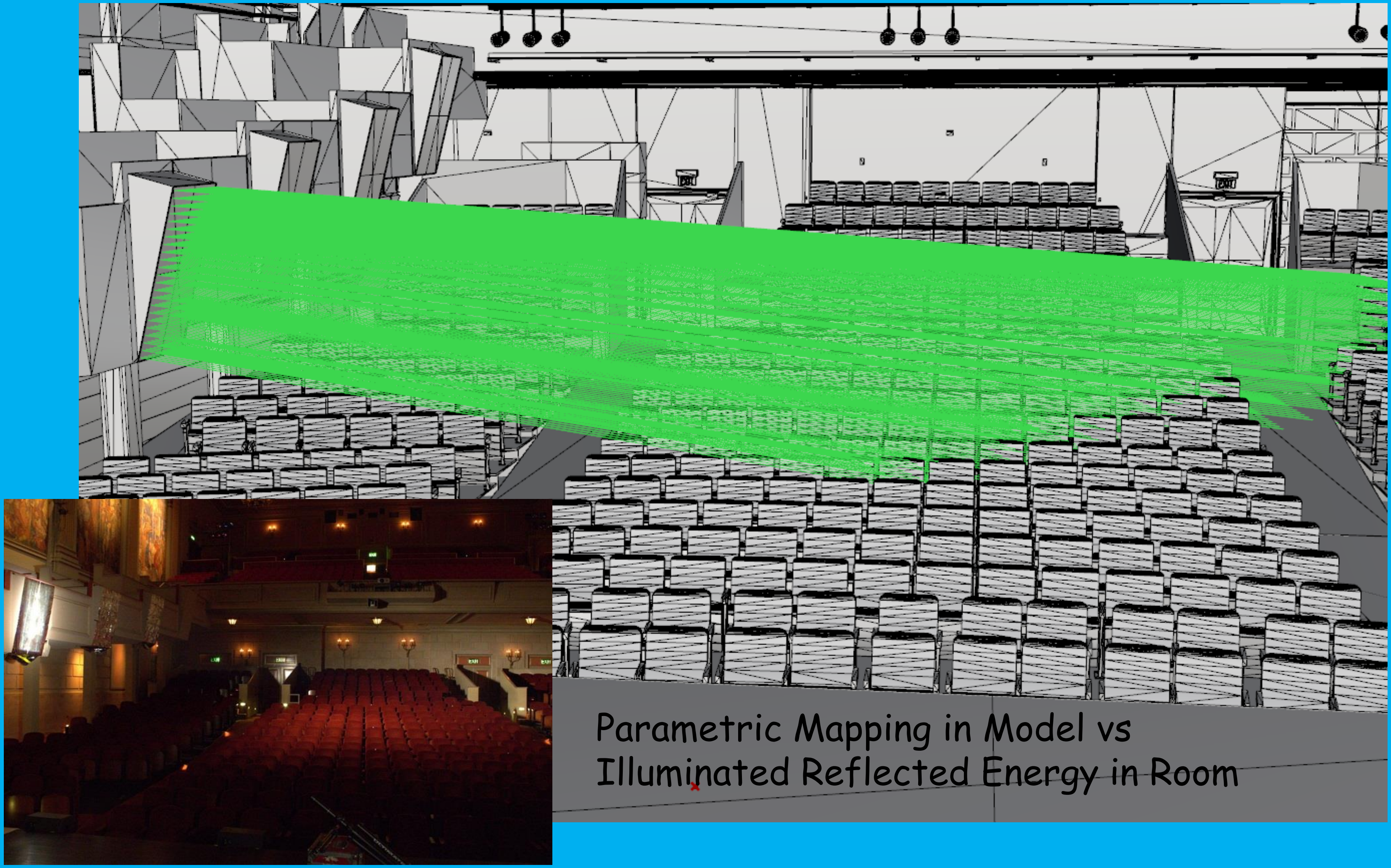
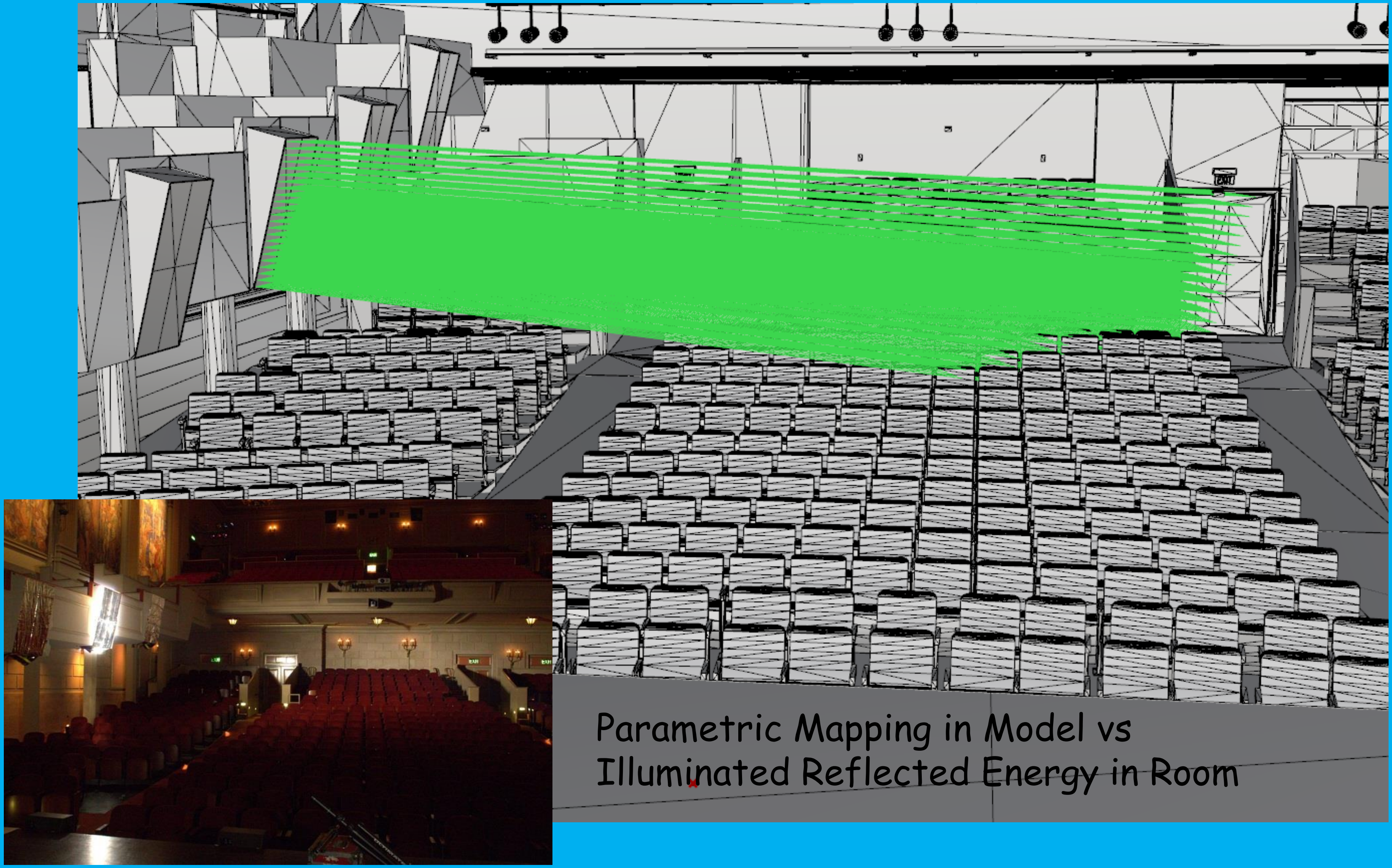
Modeling – Parametric Analysis



Parametric Mapping in Model vs Illuminated Reflected Energy in Room

Modeling – Parametric Analysis



Parametric Mapping in Model vs
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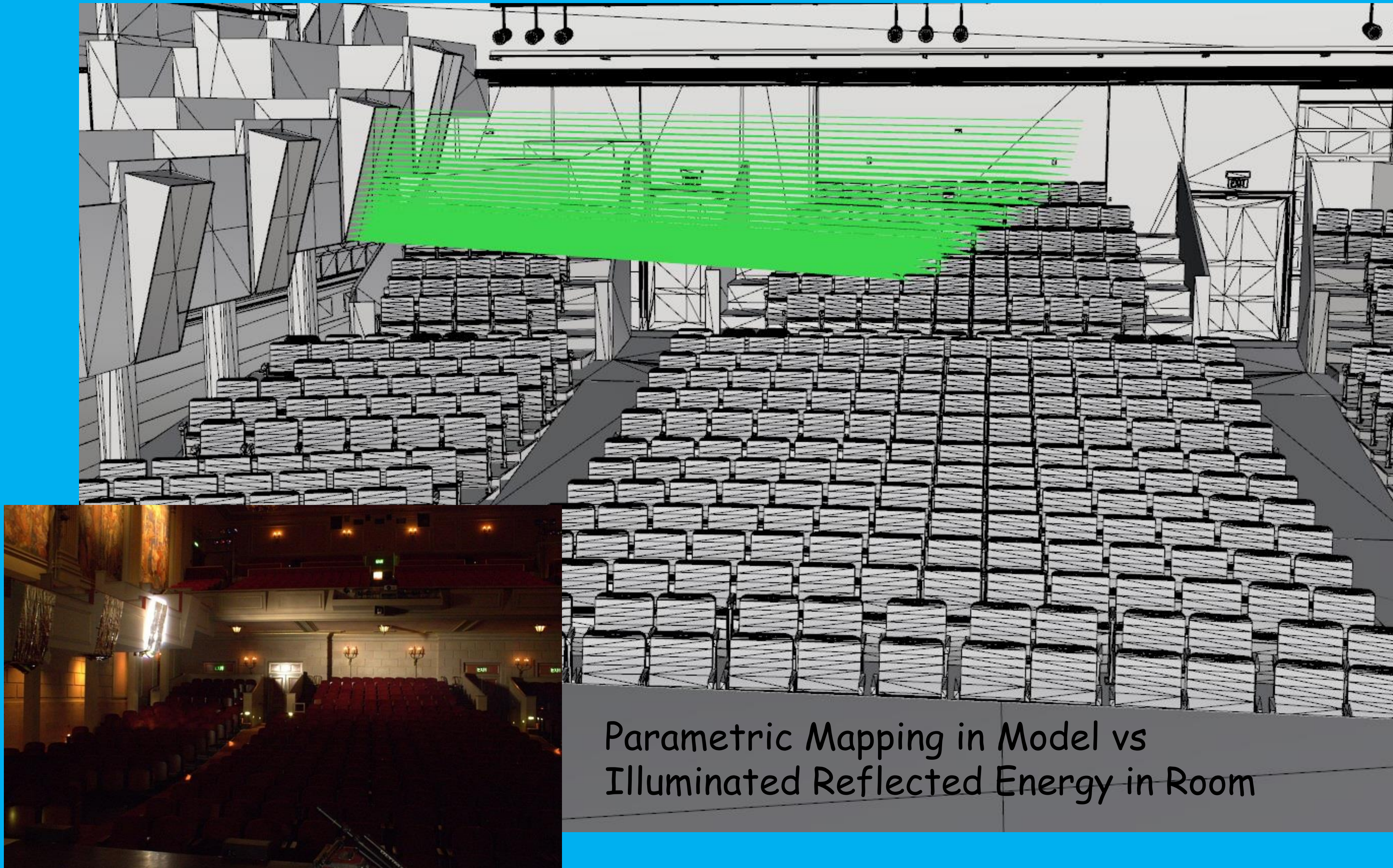
Modeling – Parametric Analysis



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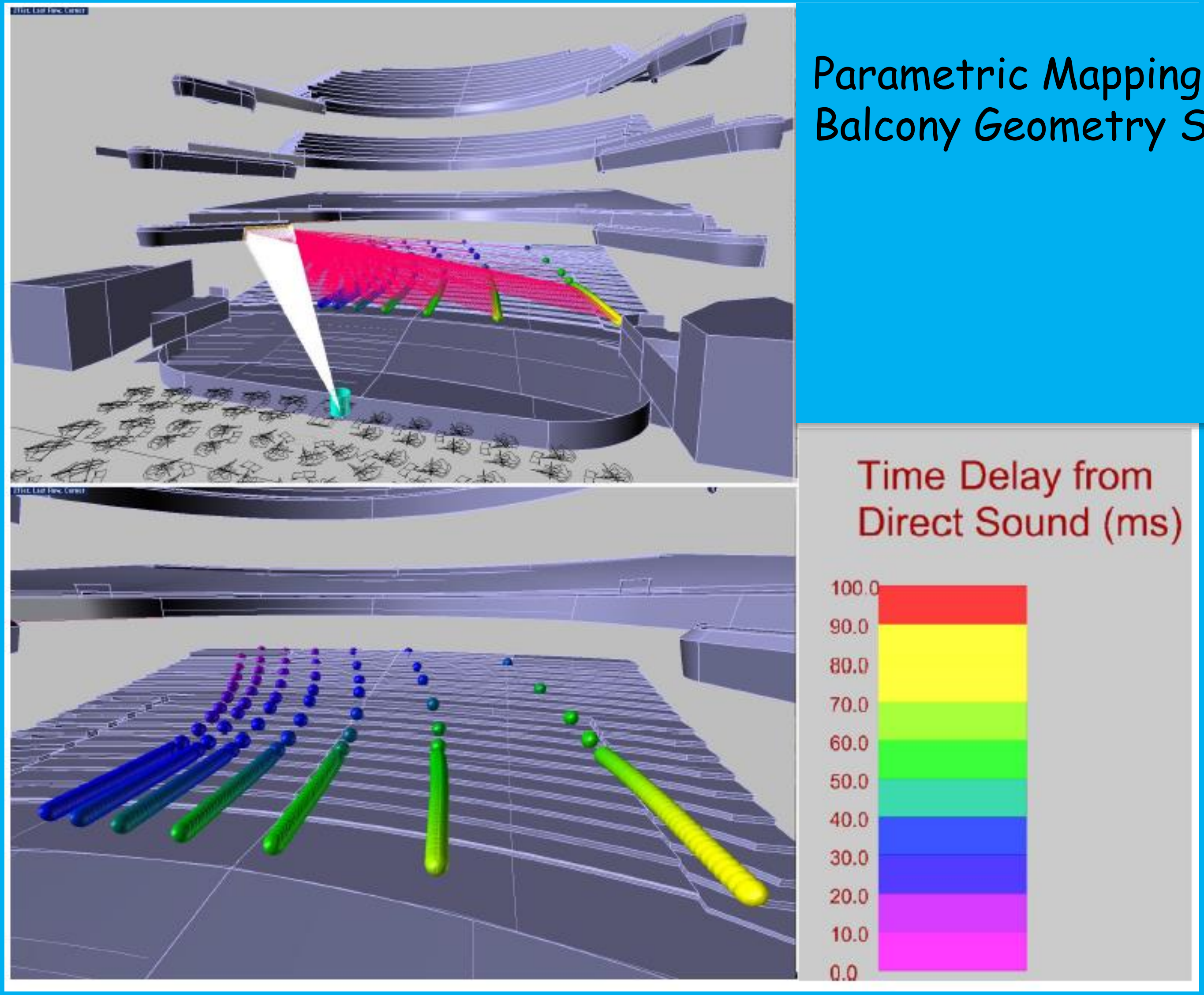

Parametric Mapping in Model for Balcony Geometry Shaping

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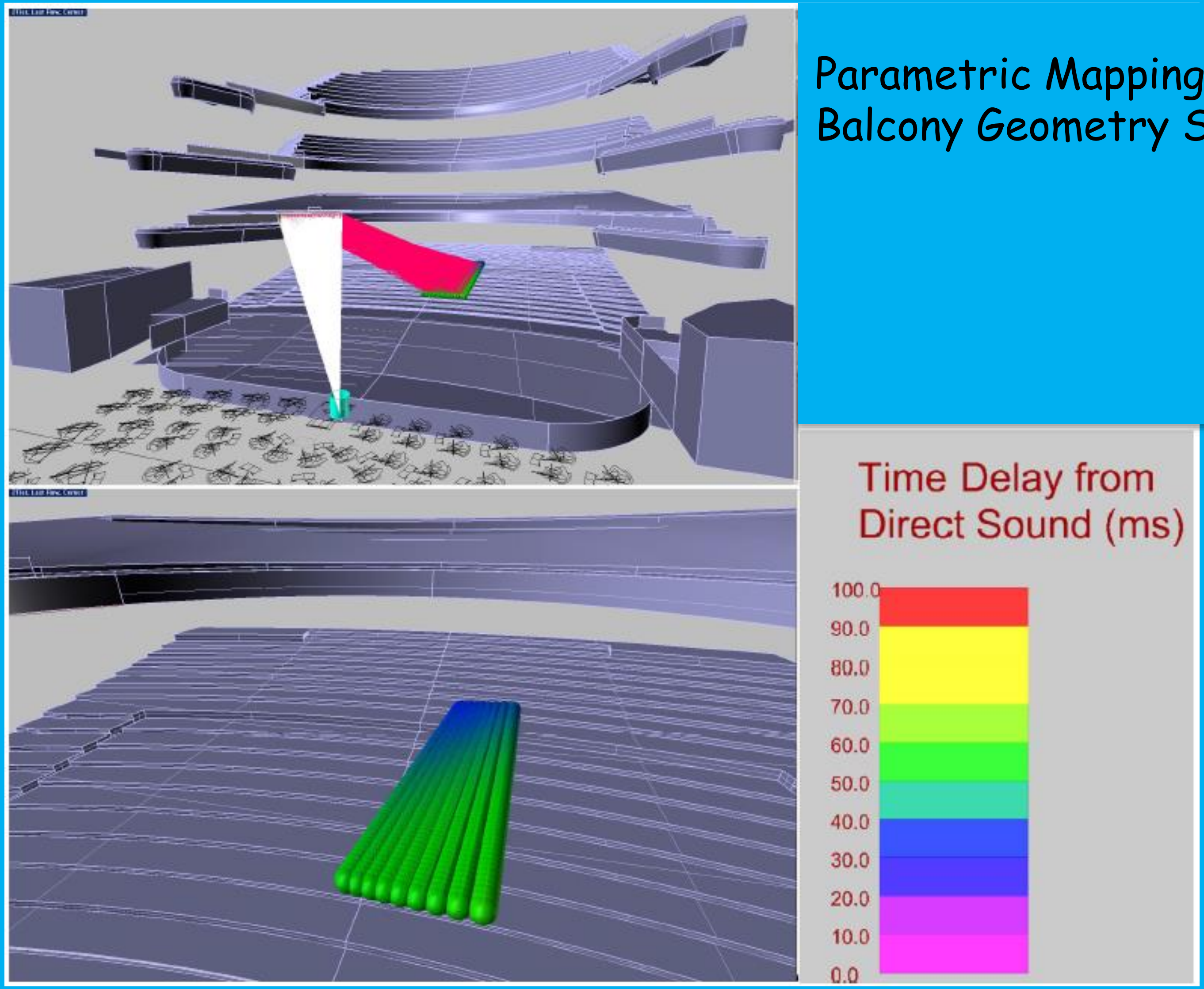
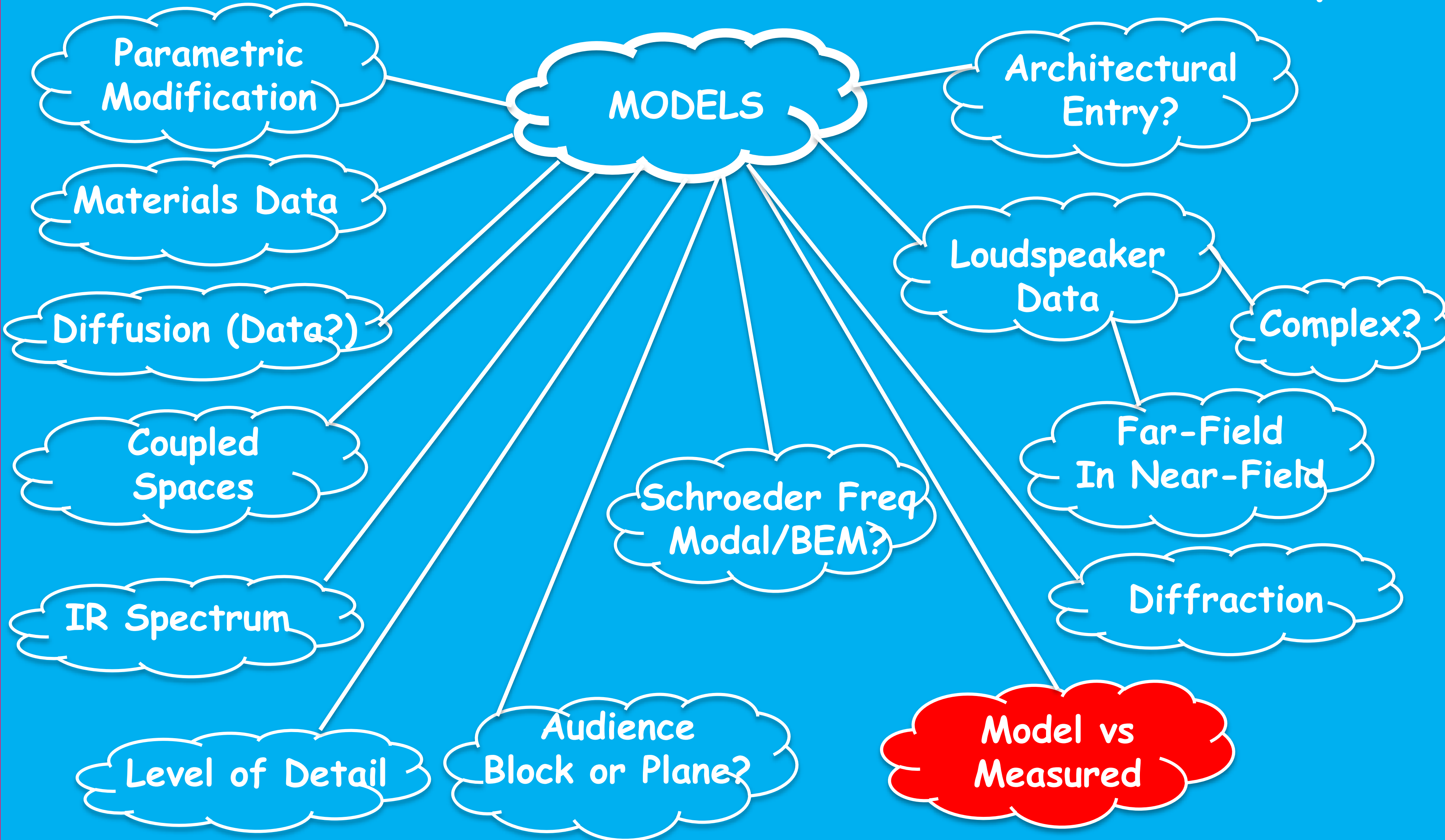
Modeling – Parametric Analysis



Parametric Mapping in Model for Balcony Geometry Shaping

Models – Just Build 'em, what Could Be Simpler?



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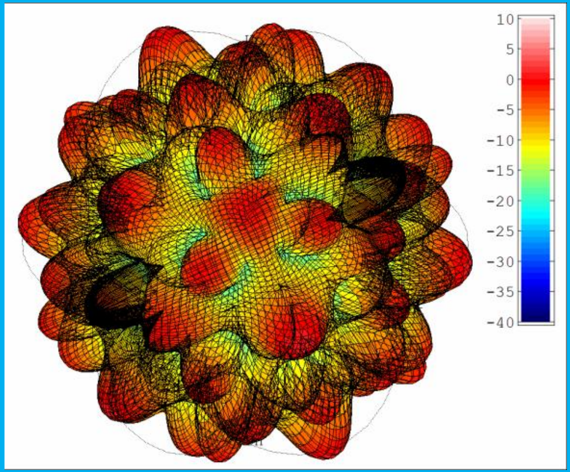
Modeling – Measured vs Modeled

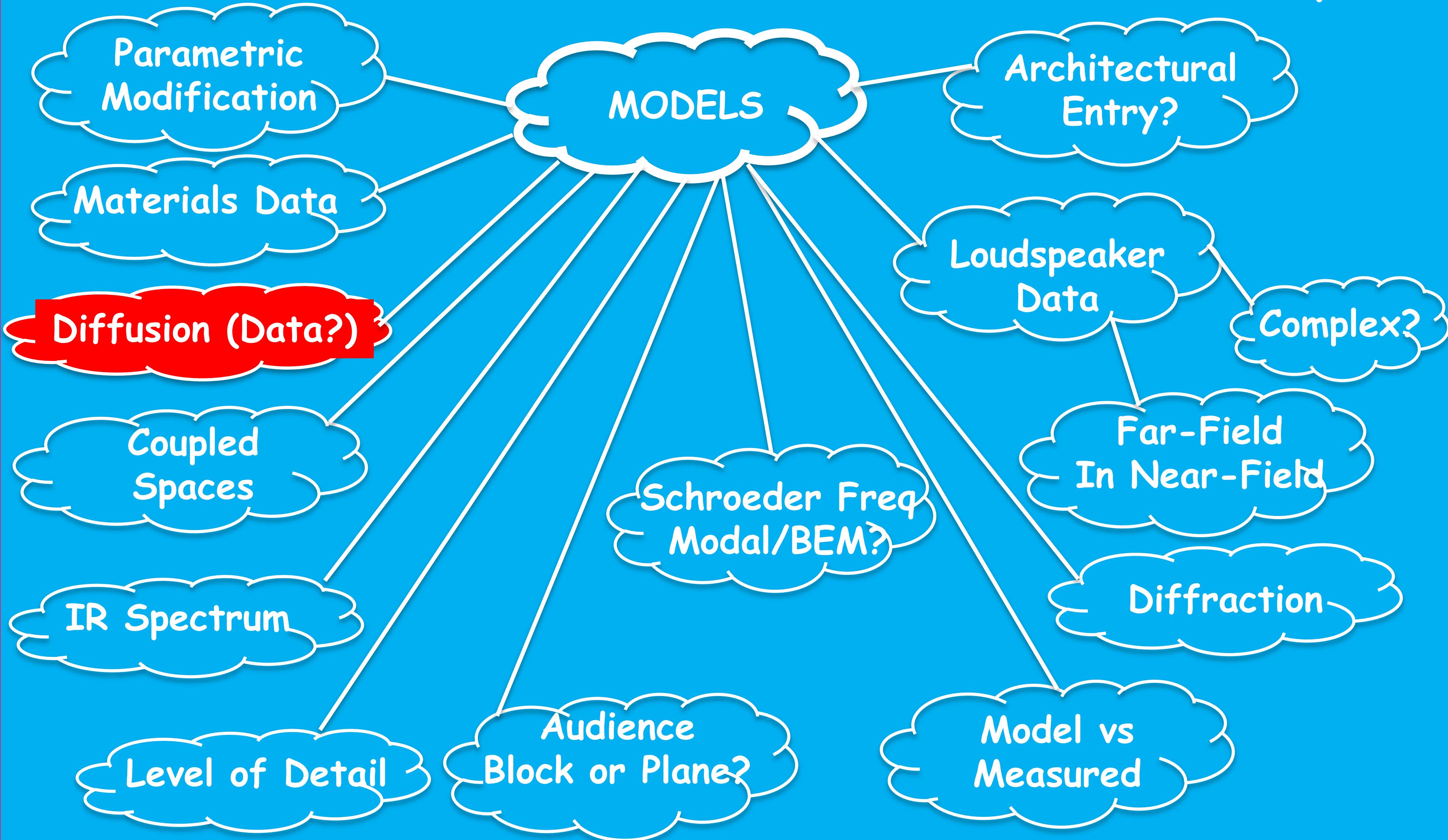
Table 2. Facts associated to measurements and simulations.

Facts	Measurements	Simulations
Room geometry	Fully included by definition	Approximated
Alteration of room geometry	Difficult	Easy
Wave phenomena (phase information, diffraction)	Fully included – inherent in the real sound field	Approximated with varying accuracy
Wall properties	Fully included – inherent in the real room	Absorption - scattering coefficients have to be measured or estimated, with limited accuracy
Air absorption (a function of temperature and humidity)	Fully included but may vary significantly in different measurements	Calculated, but very accurate
Source directivity	Not perfect: Lobes at high frequencies	Perfectly omni-directional
Dynamic range of source	Insufficient at very low and very high frequencies. Distortion at high levels	Unlimited dynamic range at all frequencies. No distortion
Calibration of source	Special procedure needed for the strength parameter, *G*	Perfect per definition
Background Noise	Limits the dynamic range, compensation necessary	Not present
Microphone directivity	Omnidirectional microphone. Some parameters require figure-of eight pattern or a dummy head	All directivities available
Results in octave-bands	Filtering is required, which alters the original signal	Results are derived directly in different bands - no alteration due to filtering
Onset time of impulse response	Critical, especially at low frequencies	Perfect per definition
Reproducibility	Not perfect: Depends heavily on the source	Can be perfect, depending on the algorithm
Influence of operator	Knowledge and experience important	Knowledge and experience very important

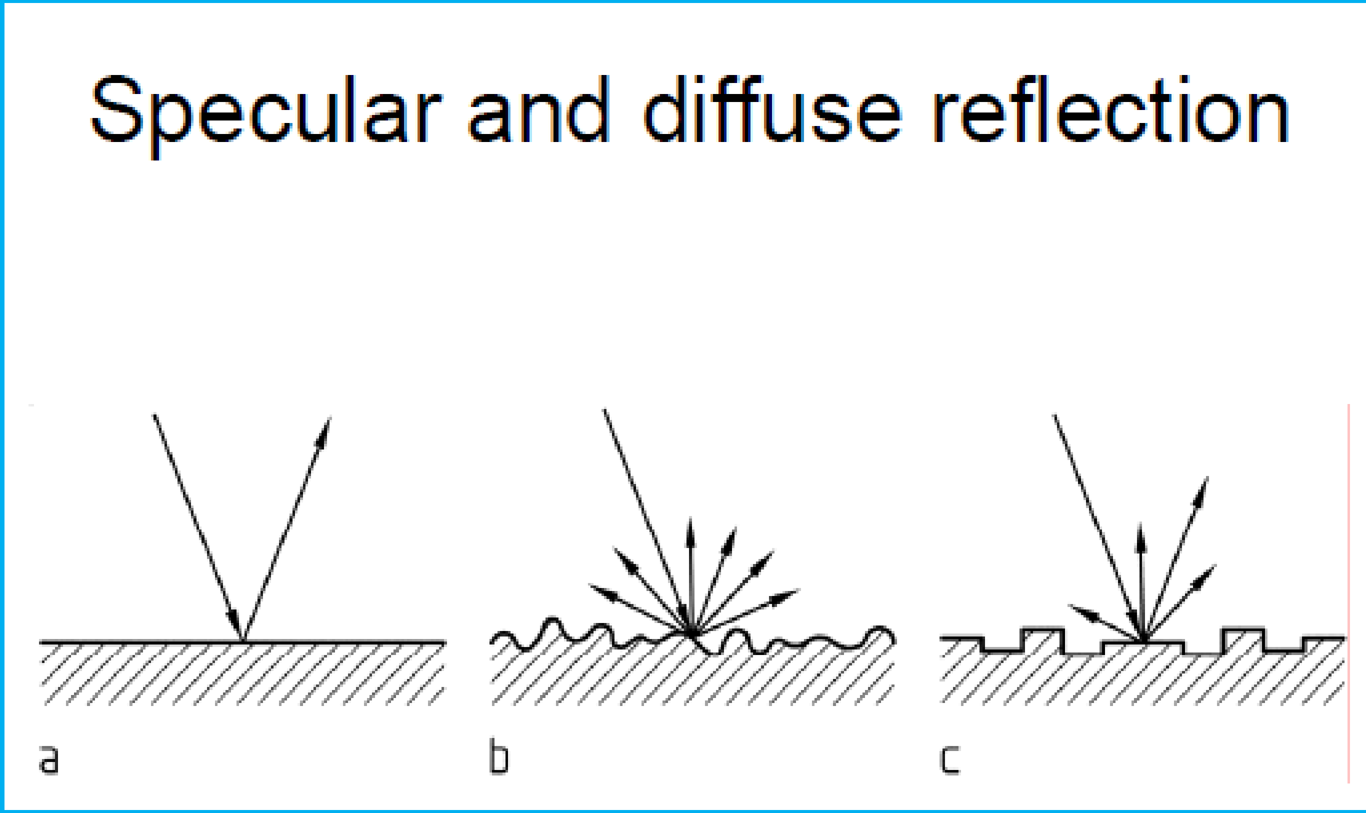


"Simulations, Measurements, & Auralizations in Architectural Acoustics", Rindel,et al_Acoustis2013

Models – Just Build 'em, what Could Be Simpler?



Modeling - Diffusion



“Simulations, Measurements, & Auralizations in Architectural Acoustics”, Rindel,et al_Acoustis 2013

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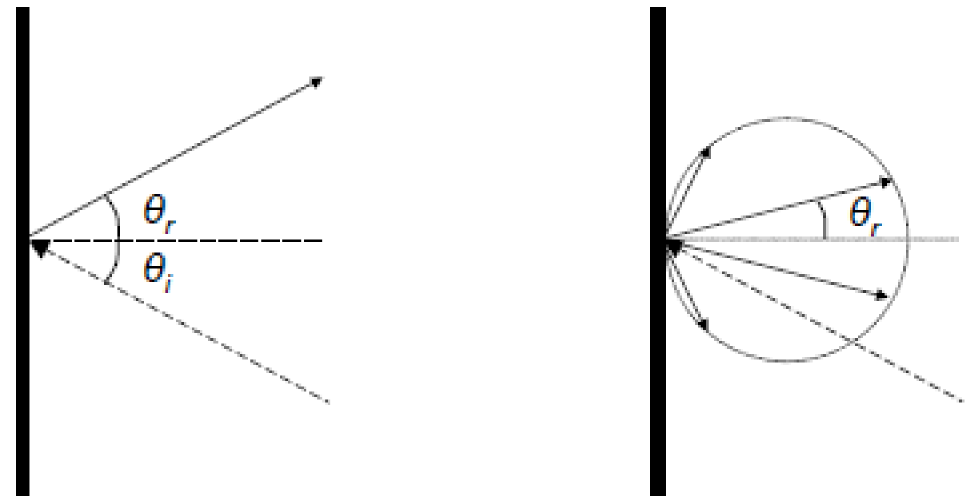
Modeling – Diffusion

Reflection models
(asymptotic models for short wavelengths)



Snell's law: $\theta_r = \theta_i$

Lambert's law:
Probability of diffuse
reflection is ~ $\cos \theta_r$

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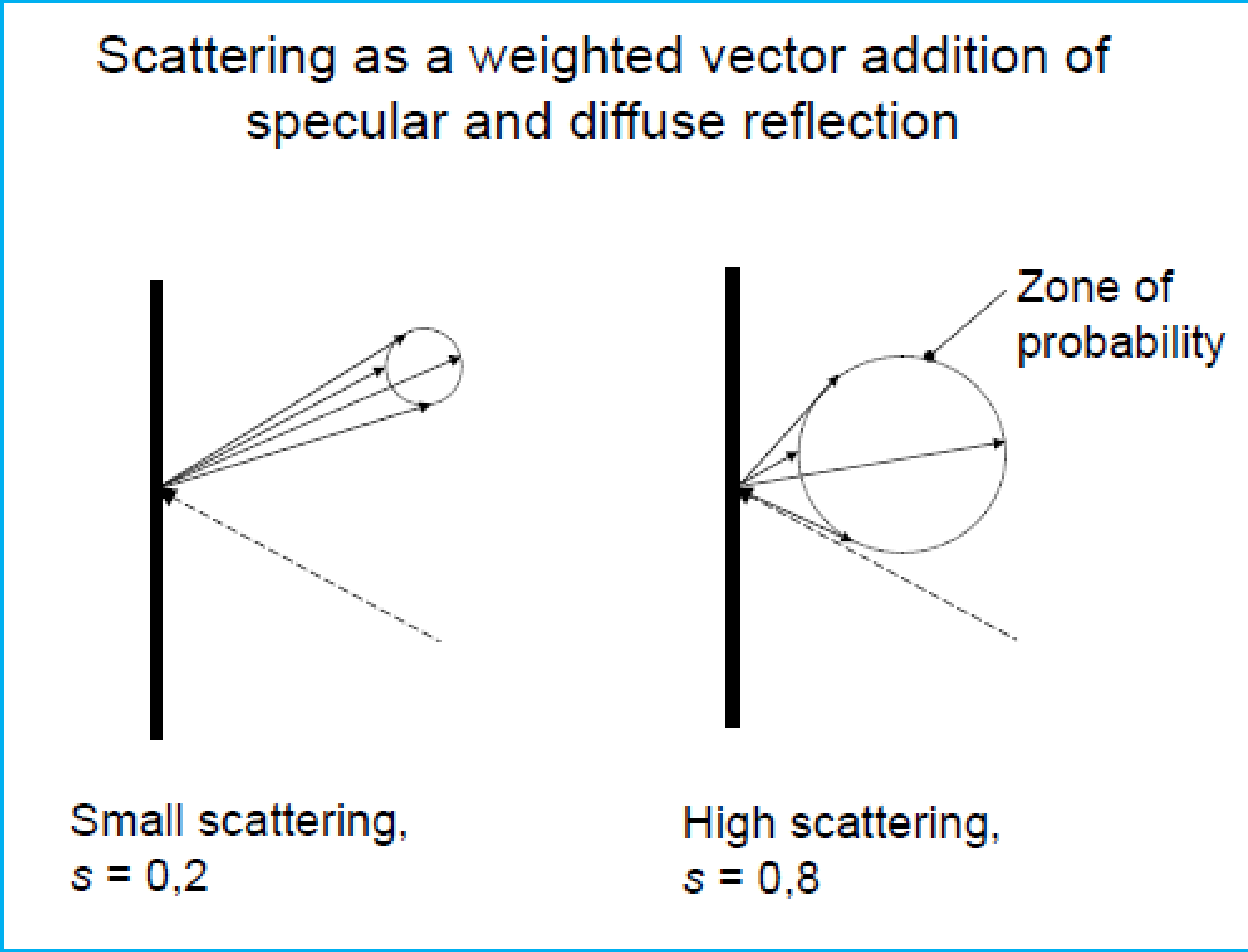
Modeling – Diffusion



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Modeling - Diffusion

Sound scattering coefficient, s

- defined as the ratio between the acoustic energy reflected in non-specular directions and the totally reflected acoustic energy
- A sound scattering surface is defined as a surface with $s \geq 0.5$

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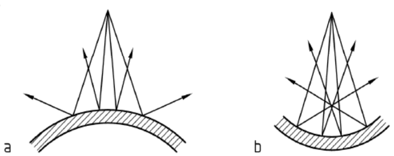
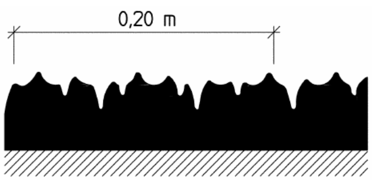
Modeling – Diffusion

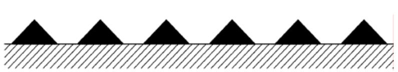
Convex and concave surfaces



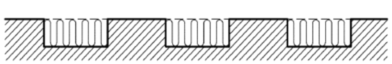
Irregular geometric structure



Periodic geometric structure



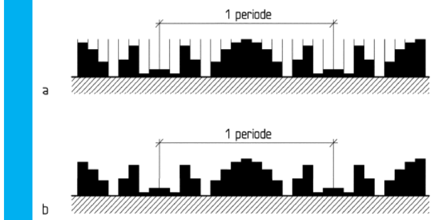
Alternating absorbing and reflecting structure



Types of diffusers

- Geometric diffusers
  - Simple curved surfaces
  - Irregular geometric structures
  - Periodic geometric structures
  - Mixture of absorbing and reflecting materials
- Mathematical diffusers
  - MLS (Maximum Length Sequence) diffusers
  - QRD (Quadratic Residue Diffusers)
  - PRD (Primitive Root Diffusers)
  - Fractal diffusers
  - Curved diffusers

QRD
Quadratic Residue Diffuser



“Simulations, Measurements, & Auralizations in Architectural Acoustics”, Rindel,et al_Acoustis 2013

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Modeling – Diffusion

Scattering Coefficients

Table III. Collection of the scattering coefficients (in ODEON) used in the acoustical models.

Scattering coefficient	Description of the surface
0.1, . . . , 0.19	large, plain surfaces
0.2, . . . , 0.39	large partially fitted surfaces
0.4, . . . , 0.59	small or fitted surfaces
0.6, . . . , 0.89	large densely fitted surfaces
0.9, . . . , 1.00	small densely fitted surfaces

“Simulations, Measurements, & Auralizations in Architectural Acoustics”, Rindel,et al_Acoustis 2013

Modeling – Diffusion

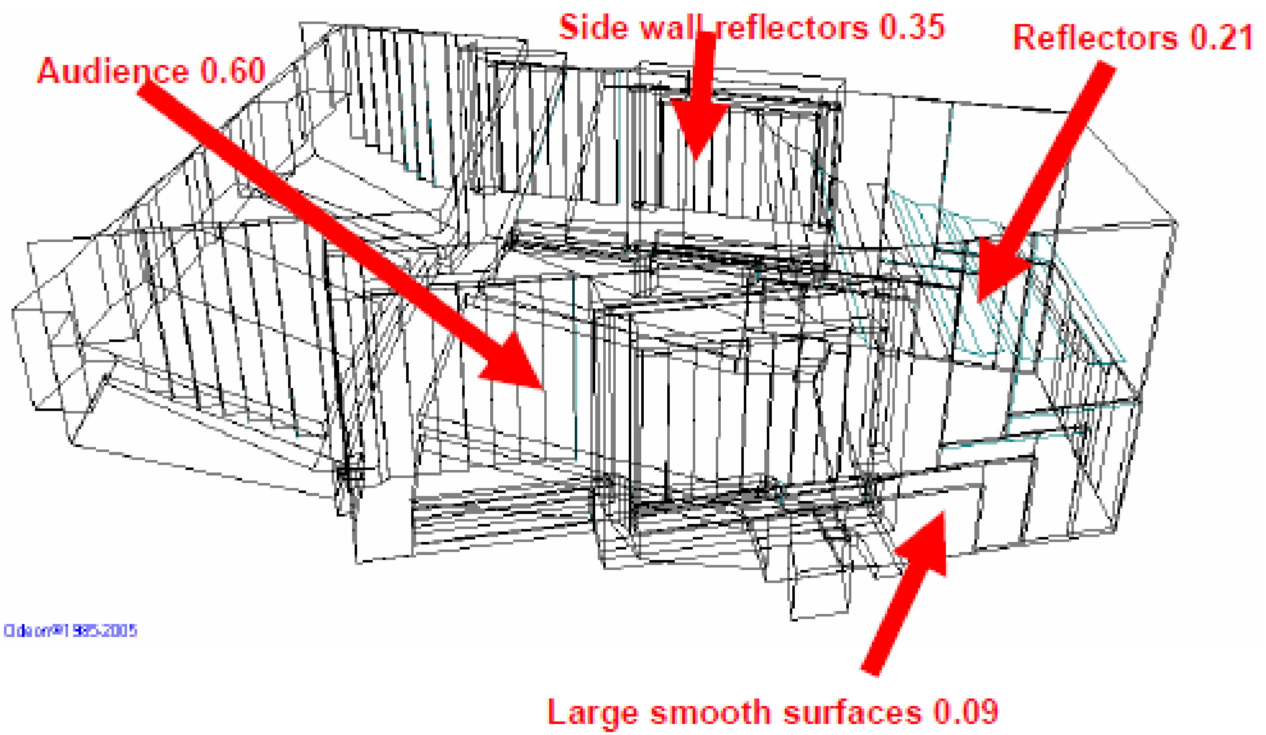

Figure 1: Example on combined scattering coefficients at 1000 Hz used in the Elmia hall, data was provided to participants in the 2nd Round Robin.

"Simulations, Measurements, & Auralizations in Architectural Acoustics", Rindel,et al_Acoustis 2013

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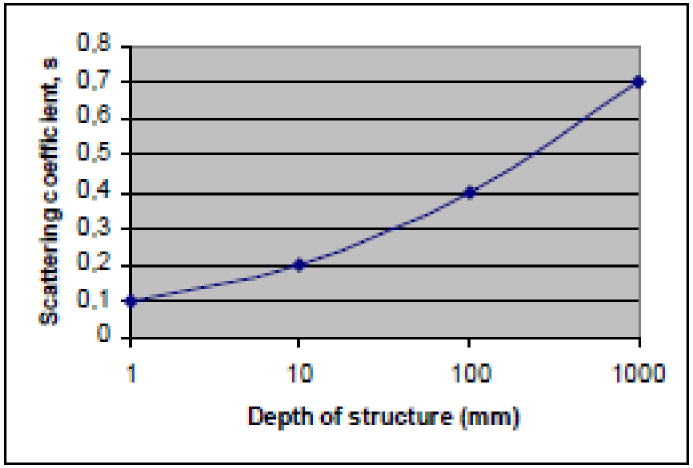
Modeling - Diffusion

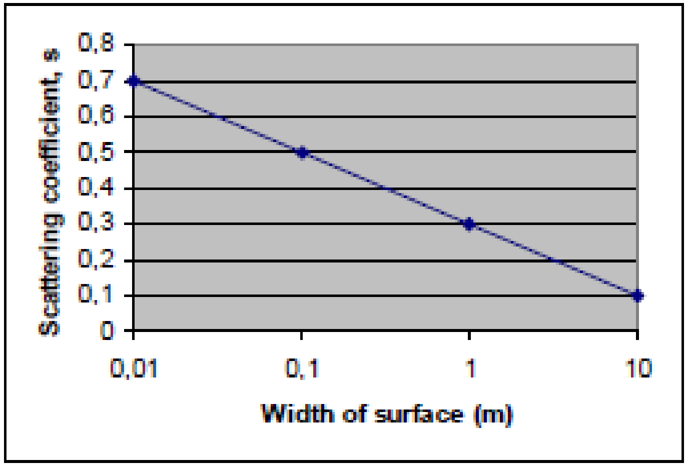
Guide to scattering coefficients

The scattering coefficient *s* should be chosen from depth of the structure and from the width of the surface.

The suggested graphs may be used as a rough guide.

The higher of the two values should be used for *s*.





“Simulations, Measurements, & Auralizations in Architectural Acoustics”, Rindel,et al_Acoustis 2013

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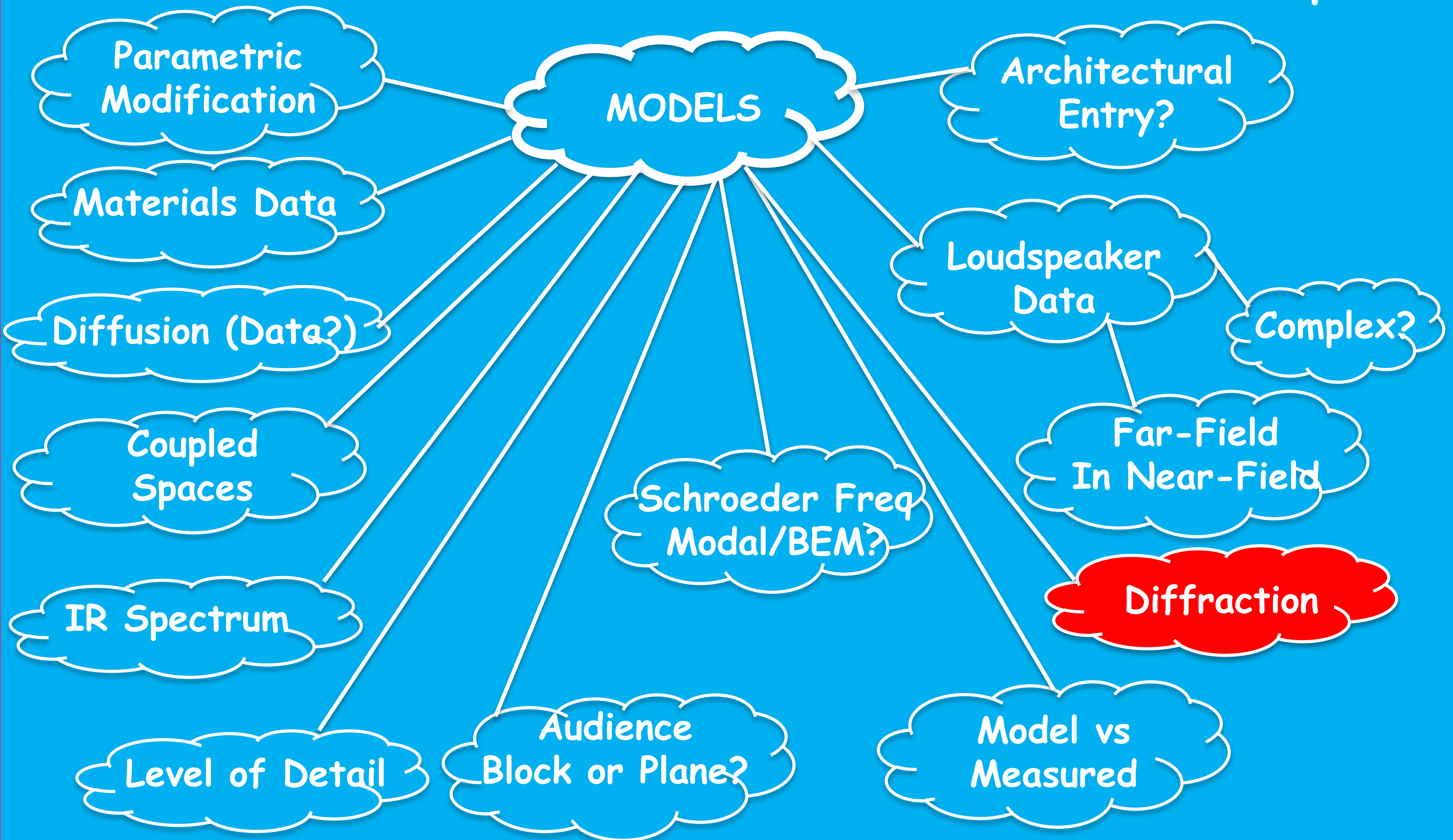
Models – Just Build 'em, what Could Be Simpler?



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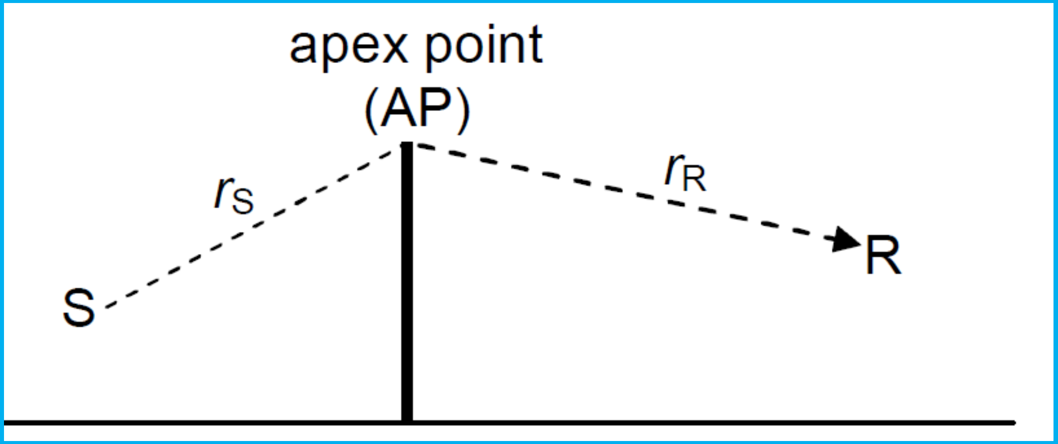
Modeling -Diffraction

- Screen-based formulas:
  - Geometric Theory of Diffraction (GTD)
  - Uniform Theory of Diffraction (UTD)



- "As all GA models, assumes edges to be large compared to the wavelength"
- Good model for environmental noise, where barriers approach infinite relative to λ
- Poor approximation of most room acoustics conditions, like:

  Reflectors, Office partitions, Orchestra Pits

"Whitepaper regarding diffraction (v5) for prediction using CATT-Acoustic v9.0c and higher", BI Dalenback

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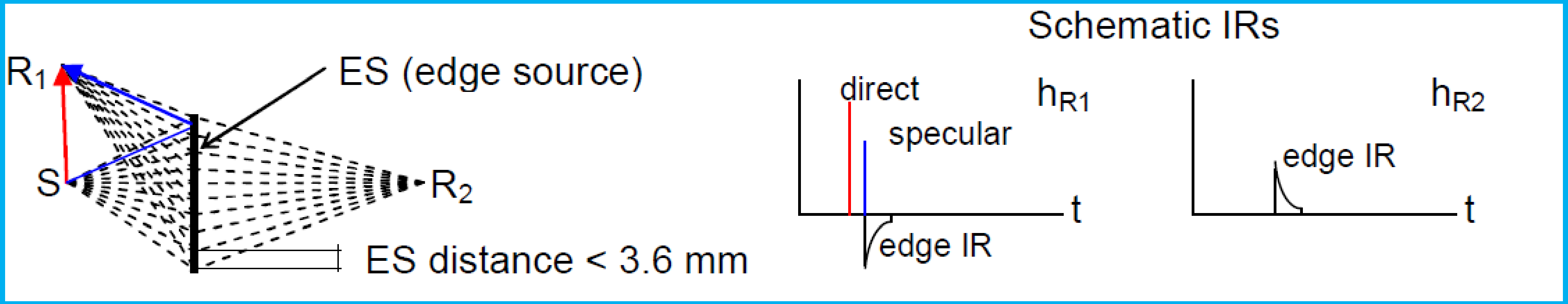
Modeling -Diffraction

- Secondary Edge Sources – CATT
  - Biot-Tolstoy Medwin/Huygens/Svensson

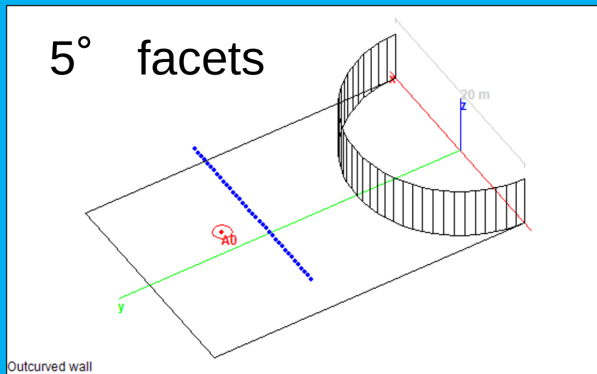


- Frequency, time and directivity of diffracted component encoded in secondary
- edge IR (screen-based models assume a frequency-dependent pulse)
- Diffracted component included in receivers on local side of edge (which is true!)
- No practical limitation of edge length, S/R angle/location, panel size
- As a bonus, CATT adds source directivity + absorption profile to the mix

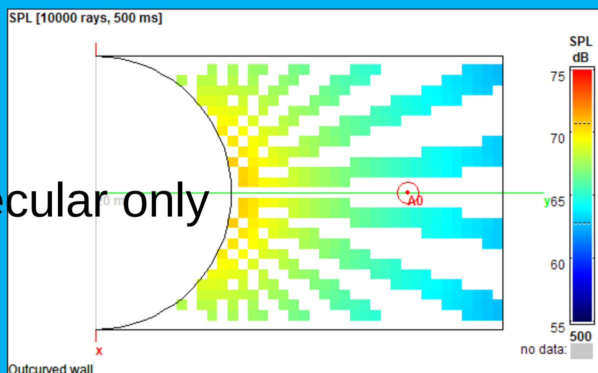
“Whitepaper regarding diffraction (v5) for prediction using CATT-Acoustic v9.0c and higher”, BI Dalenback

Modeling –Diffraction

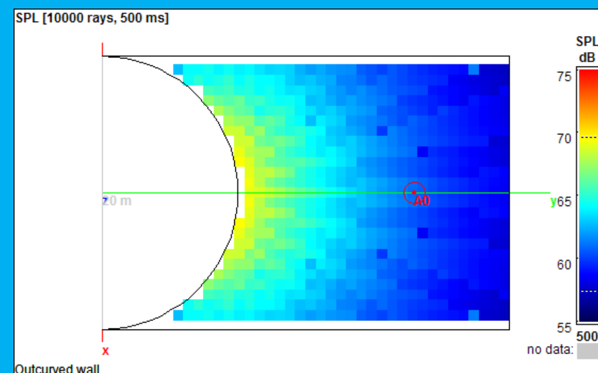
5° facets



Specular only



With Diffraction

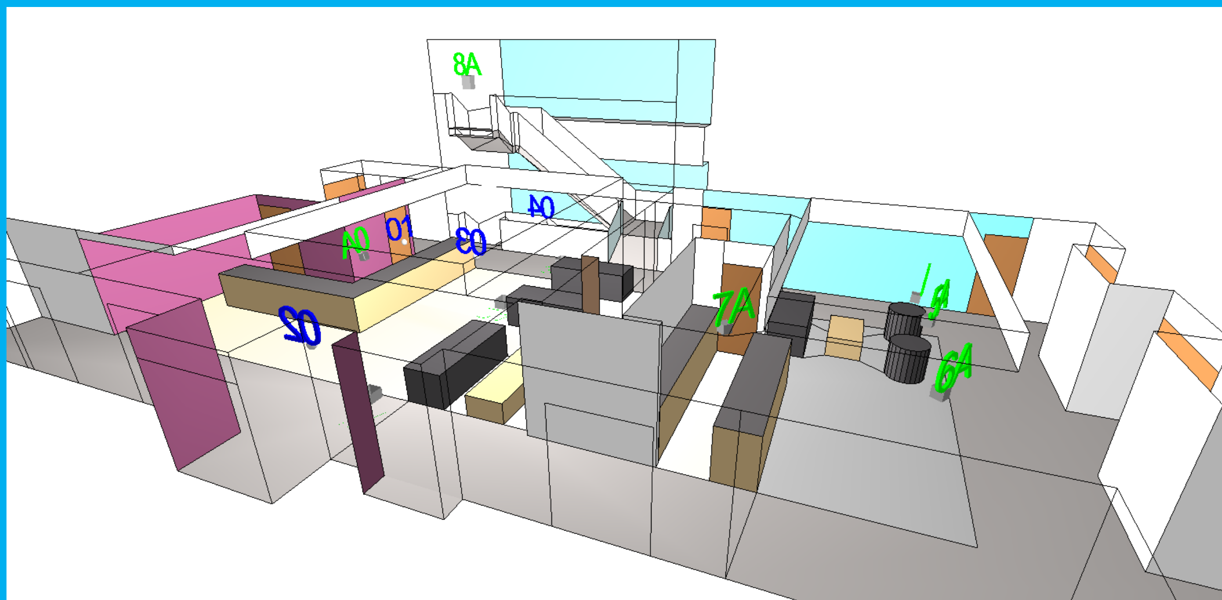


"With the 5° approximation the correct behavior is in this example achieved up to about 1 kHz while for higher frequencies the approximation is not sufficient and sectors will be seen (but no gaps like with specular-only - just weaker reflections). However, unlike the purely specular GA case, with the SES method it in this case helps to use a better approximation and using 2.5° will roughly double the frequency to 2 kHz where a more correct smooth reflection will be achieved."

"Whitepaper regarding diffraction (v5) for prediction using CATT-Acoustic v9.0c and higher", BI Dalenback

Modeling -Diffraction

BUT...is the difference significant enough to justify the increased time?



- 40k rays
- 1s IR Time
- 2nd algorithm
- 2nd order diffraction
- 9 sources
- 4 receivers
- **40 Hours**

- 40k rays
- 1s IR Time
- 2nd algorithm
- 2nd order diffraction
- 5 sources
- 4 receivers
- **12 Hours**

- 40k rays
- 1s IR Time
- 2nd algorithm
- No diffraction
- 5 sources
- 4 receivers
- **12 Hours**

- 80k rays
- 1s IR Time
- 1st algorithm
- 2nd order diffraction
- 5 sources
- 4 receivers
- **2 Hours**

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Auralisation

Phrase coined by Mendel Kleiner of Chalmers University:

- "Auralization is the process of rendering audible, by physical or mathematical modeling, the sound field of a source in a space, in such a way as to simulate the binaural listening experience at a given position in the modeled space."

"Auralization – An Overview", Kleiner et al, JAES, Vol 41, No 11, 1993 November

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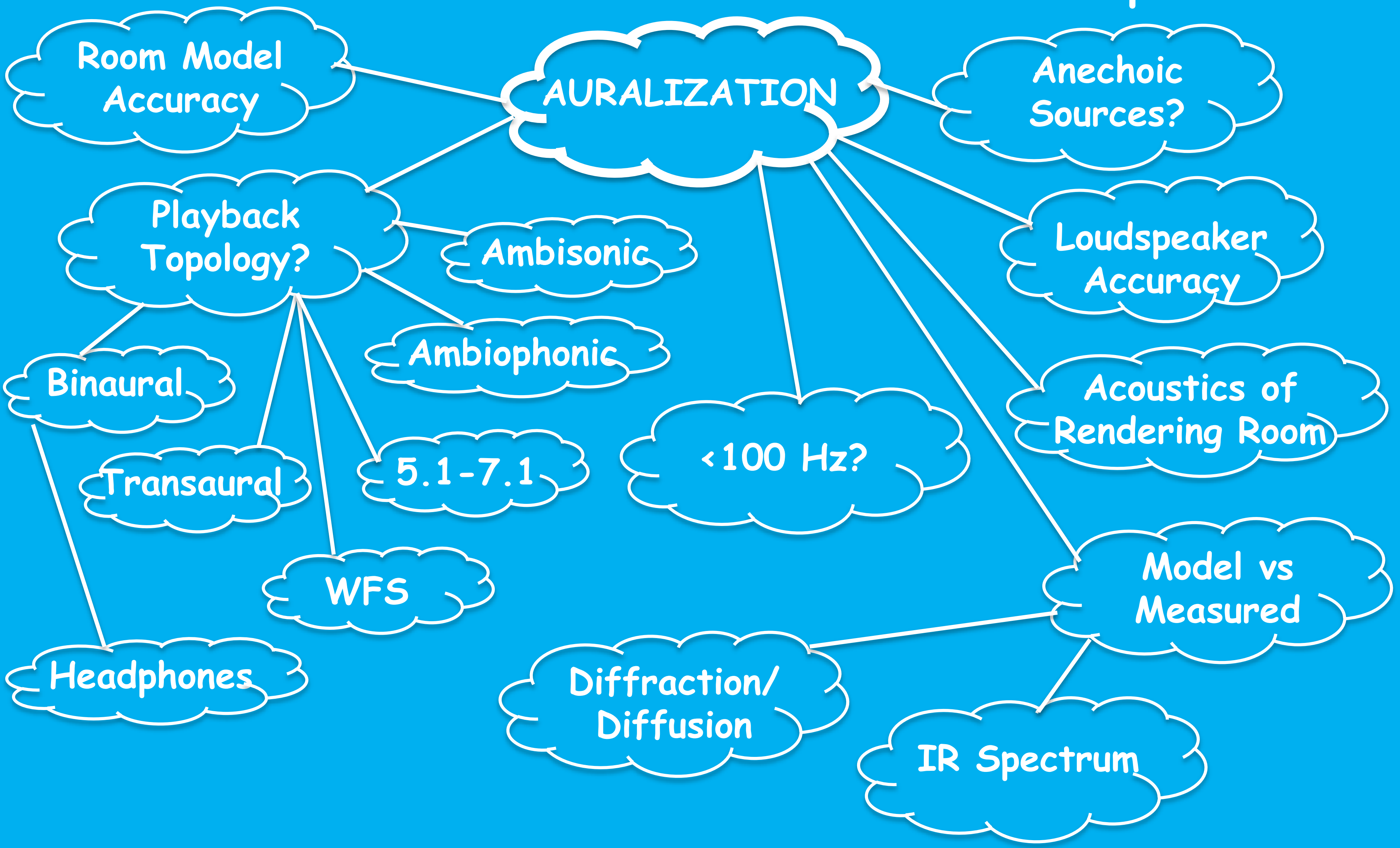
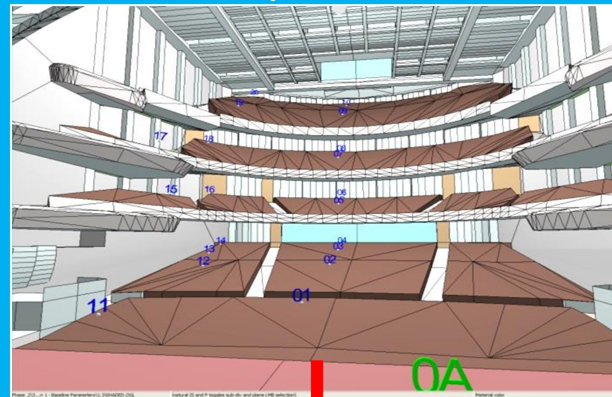
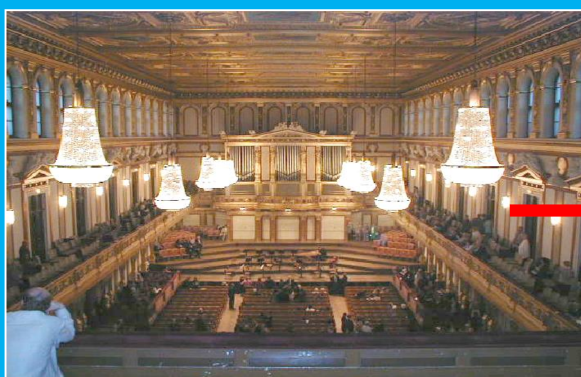
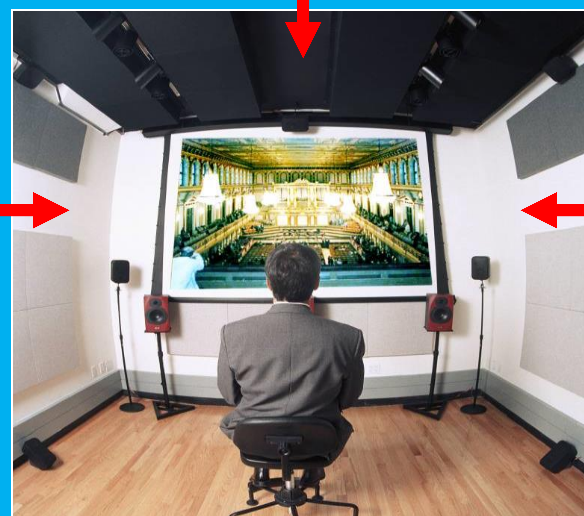
Auralization – What Could Be Simpler?

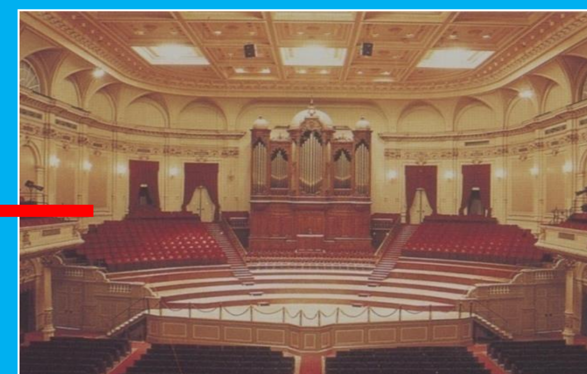


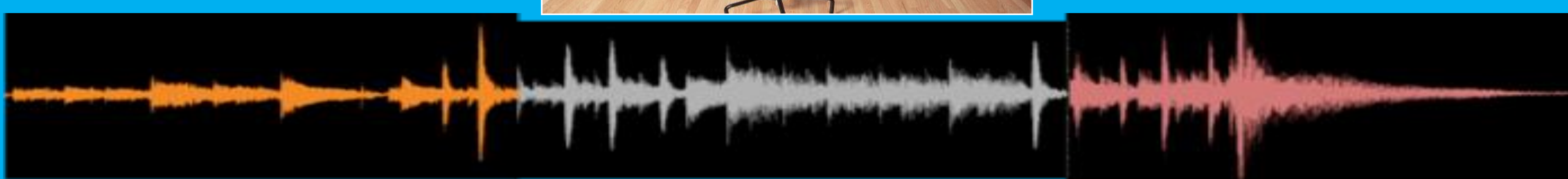
Auralisation – Arup SoundLab











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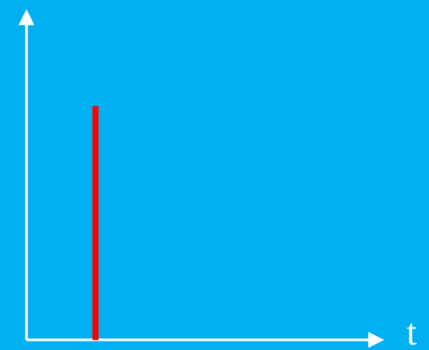
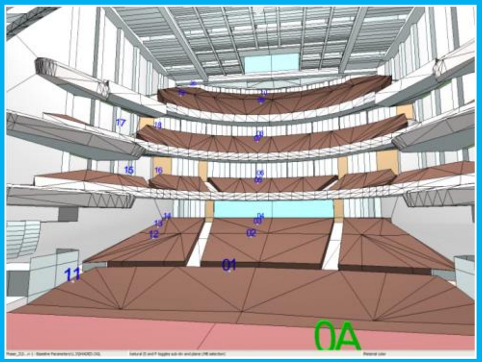
Auralisation - Methodology

Impulse



Real Room or Computer Model



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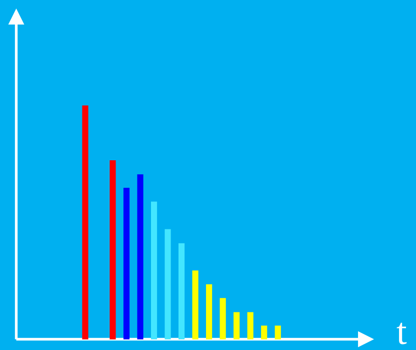
Impulse Response

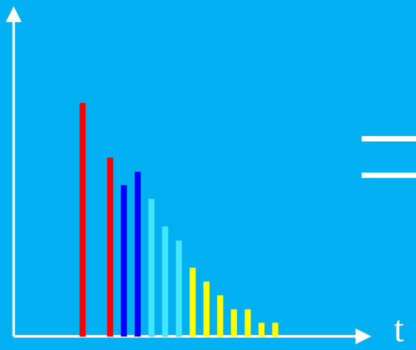


Auralisation

Anechoic Music

×

Impulse Response



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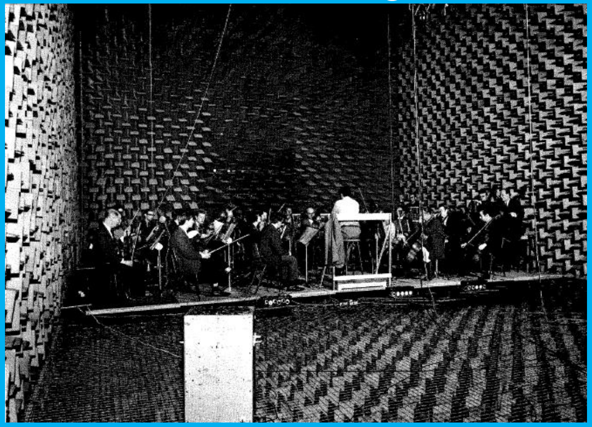
Listen in SoundLab

Auralisation – Arup SoundLab

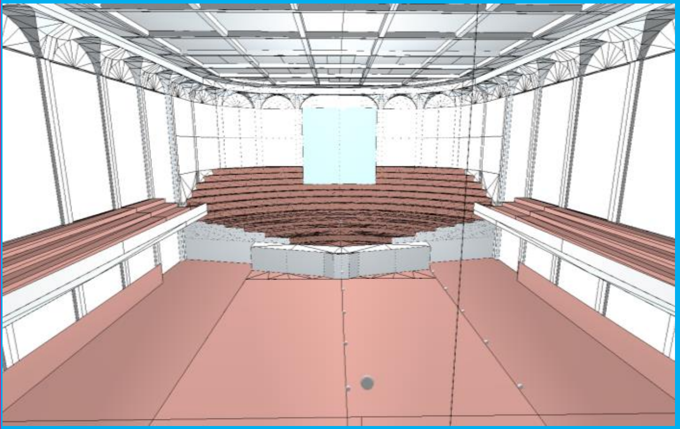
Site Acoustic Measurements

Convolve with Anechoic Recording



Listen

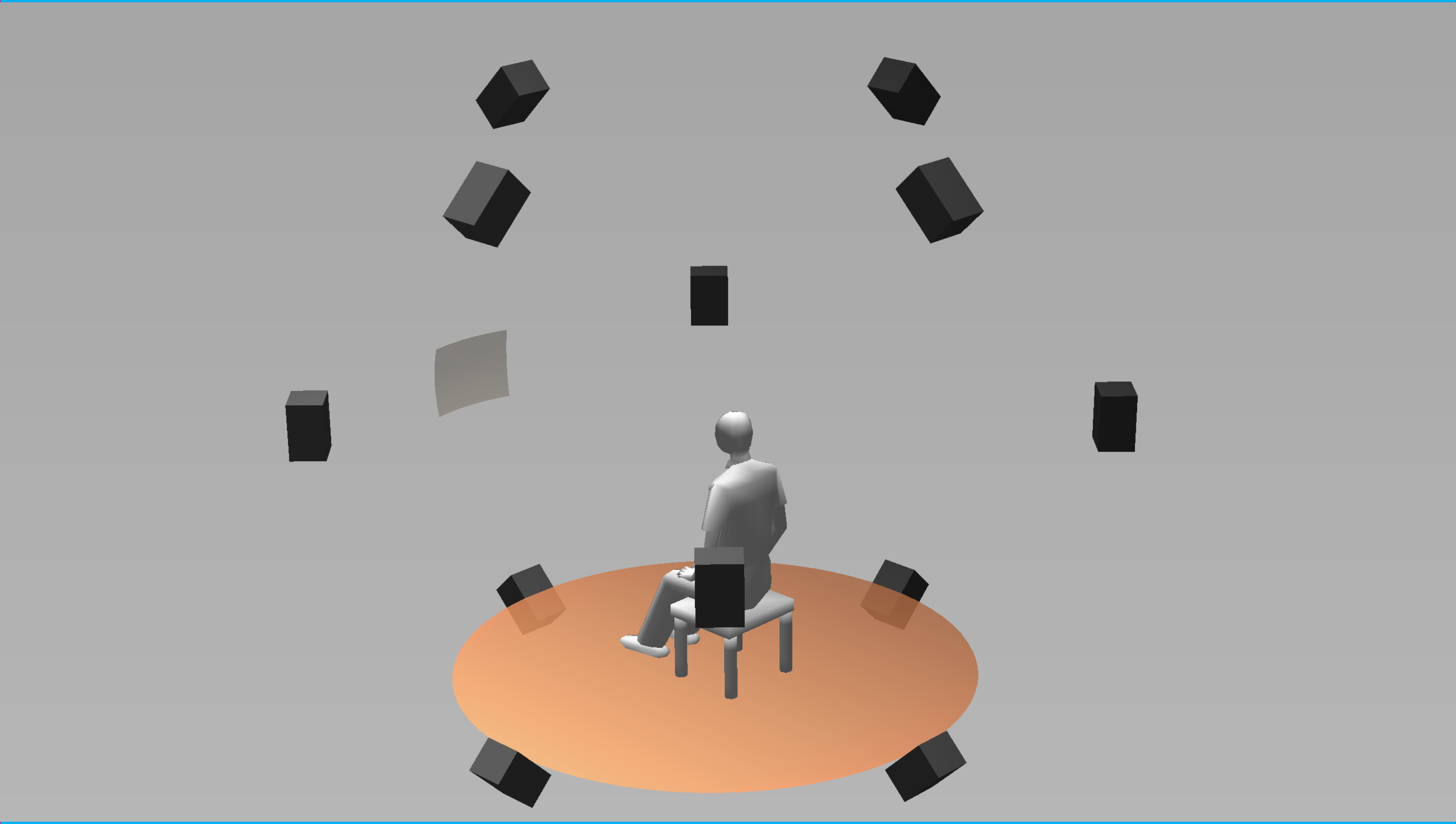
Data from 3D Acoustic Model



Convolve with Anechoic Recording

Listen

Auralisation – Monaural



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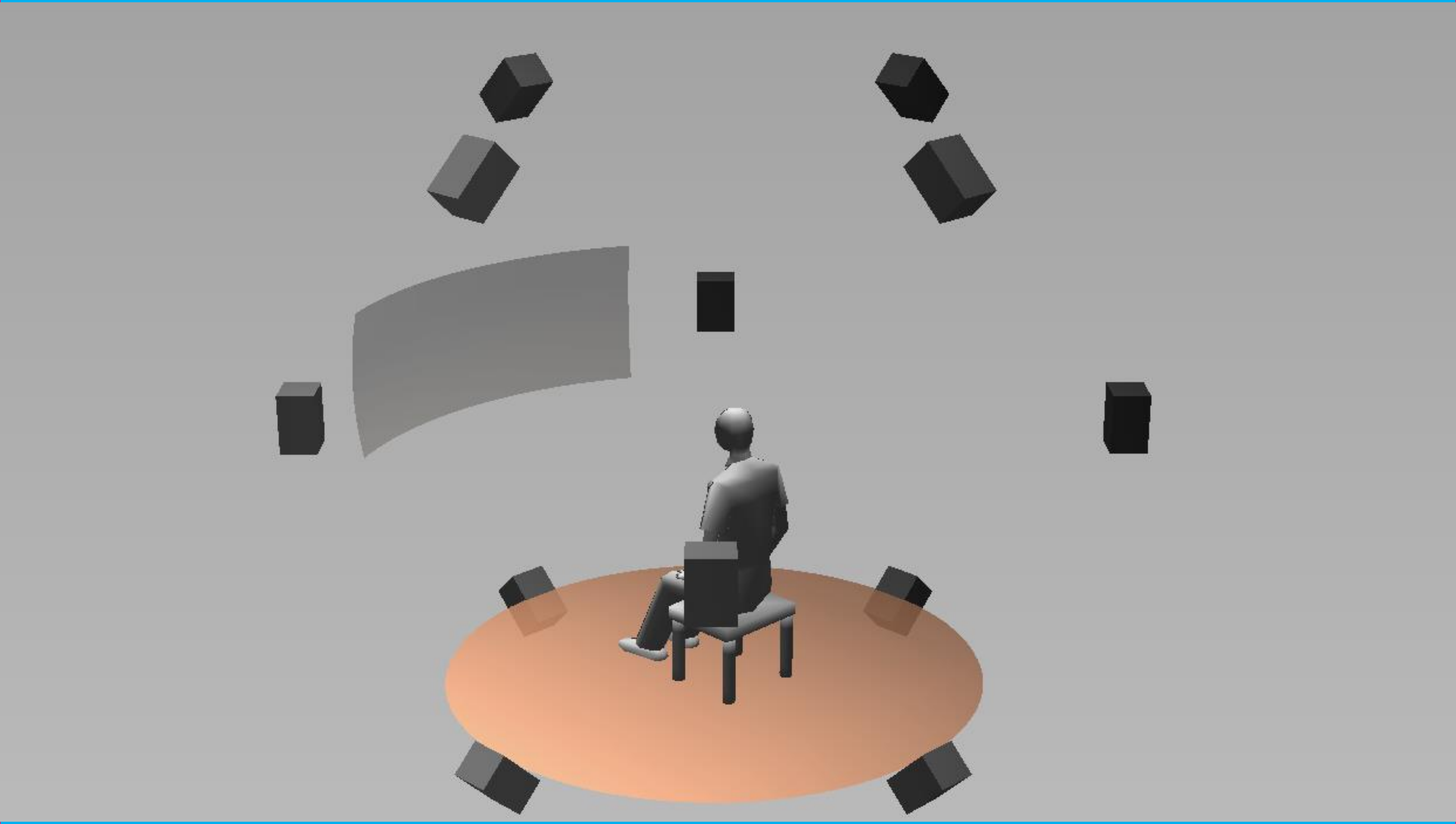
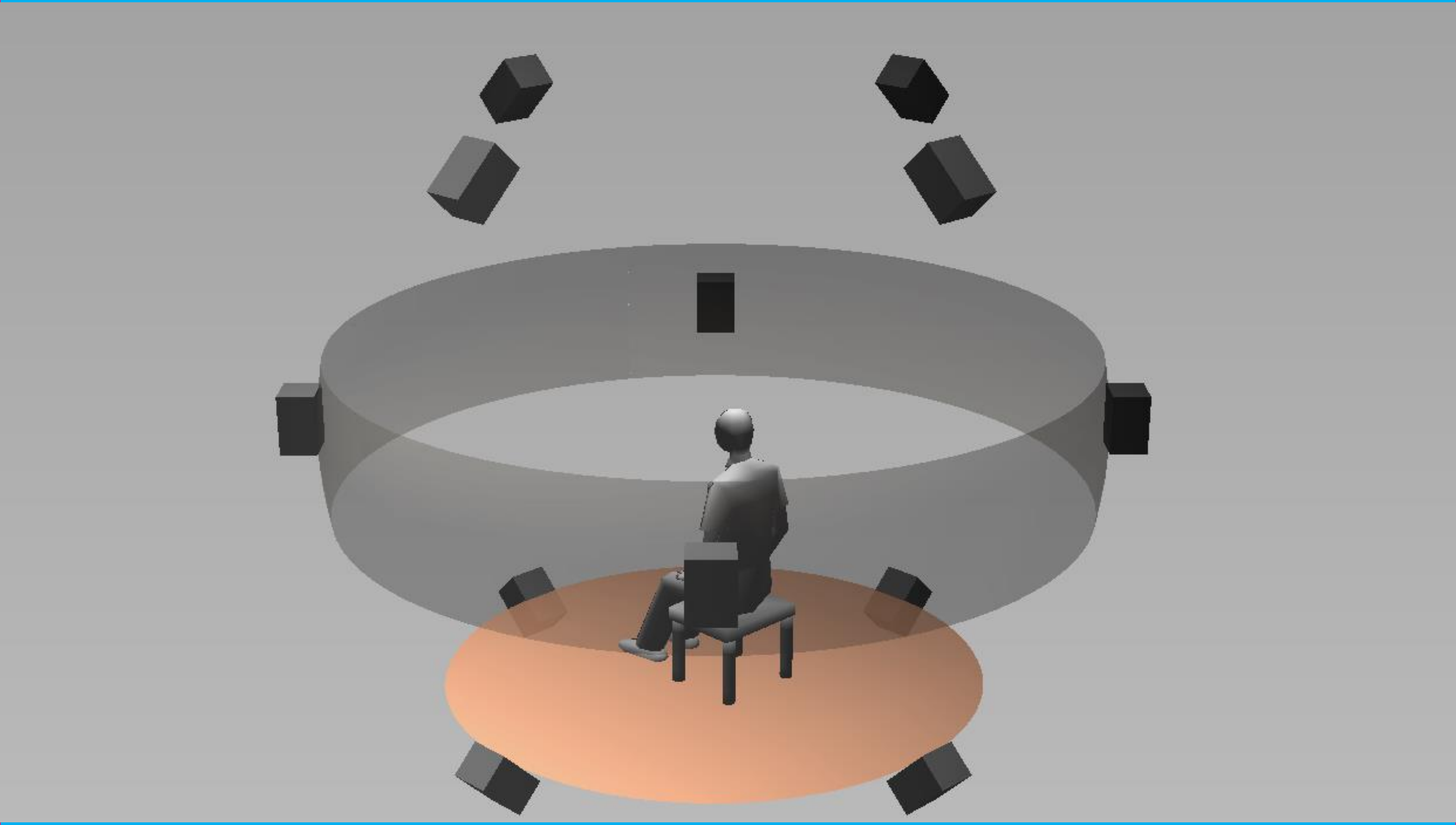
Auralisation - Stereo / Transaural



Auralisation - 5.1/7.1 Surround



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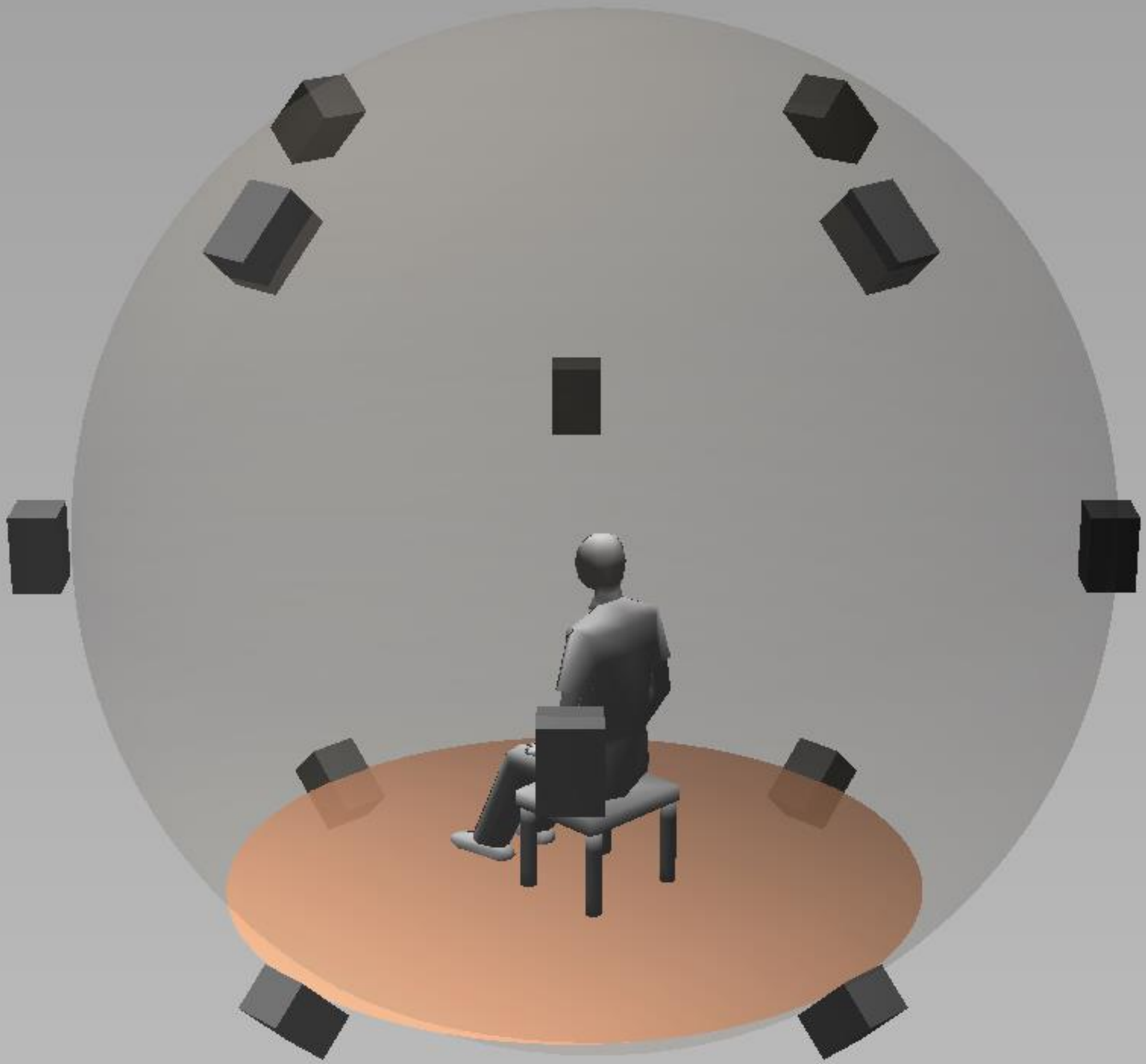
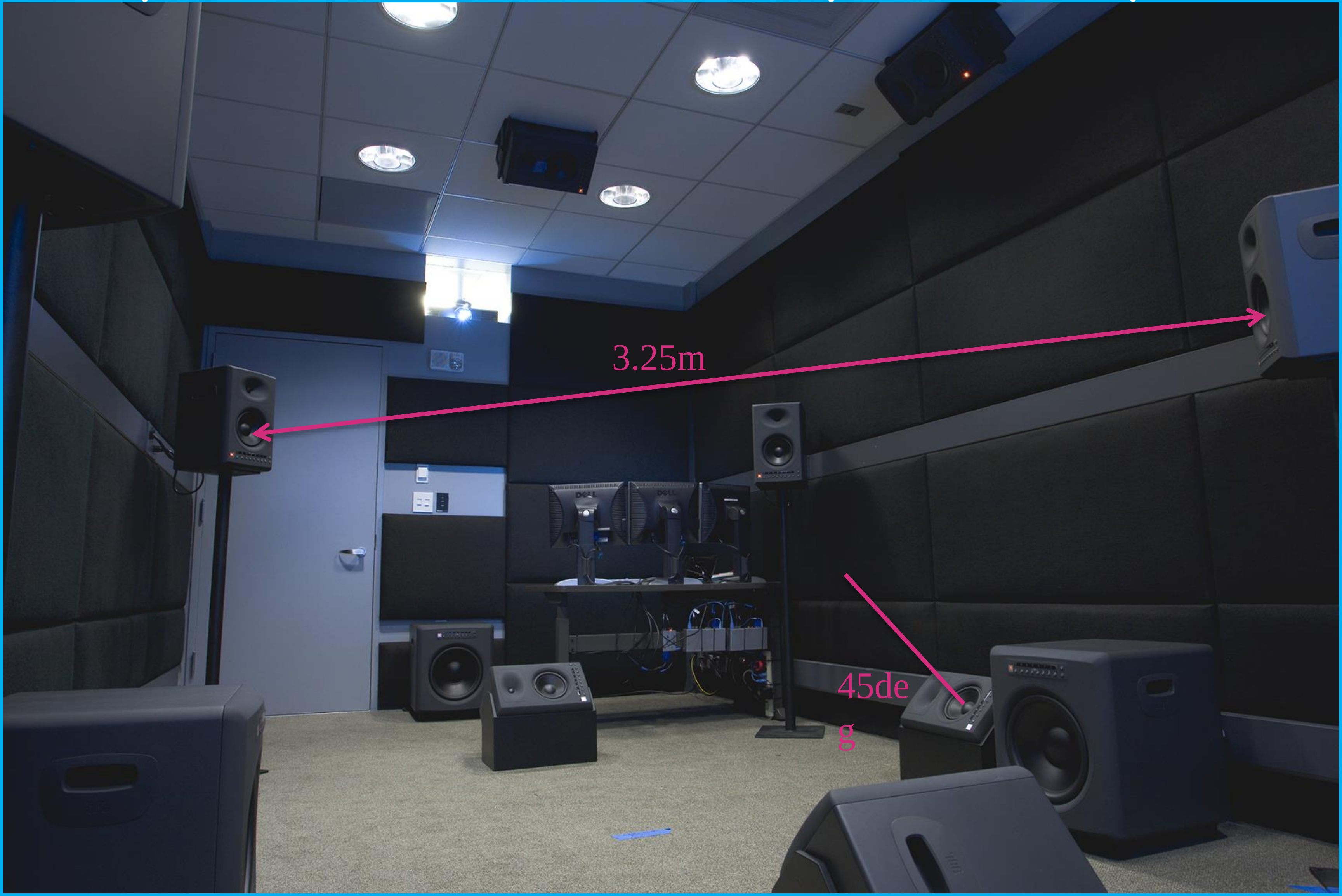
Auralisation – Ambisonic



Arup SoundLab SF- Loudspeaker Layout



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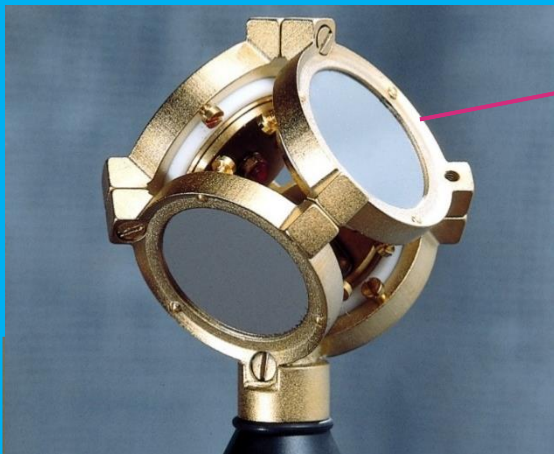
SoundLab SF- Hardware



Soundfield mic

B&K SLM

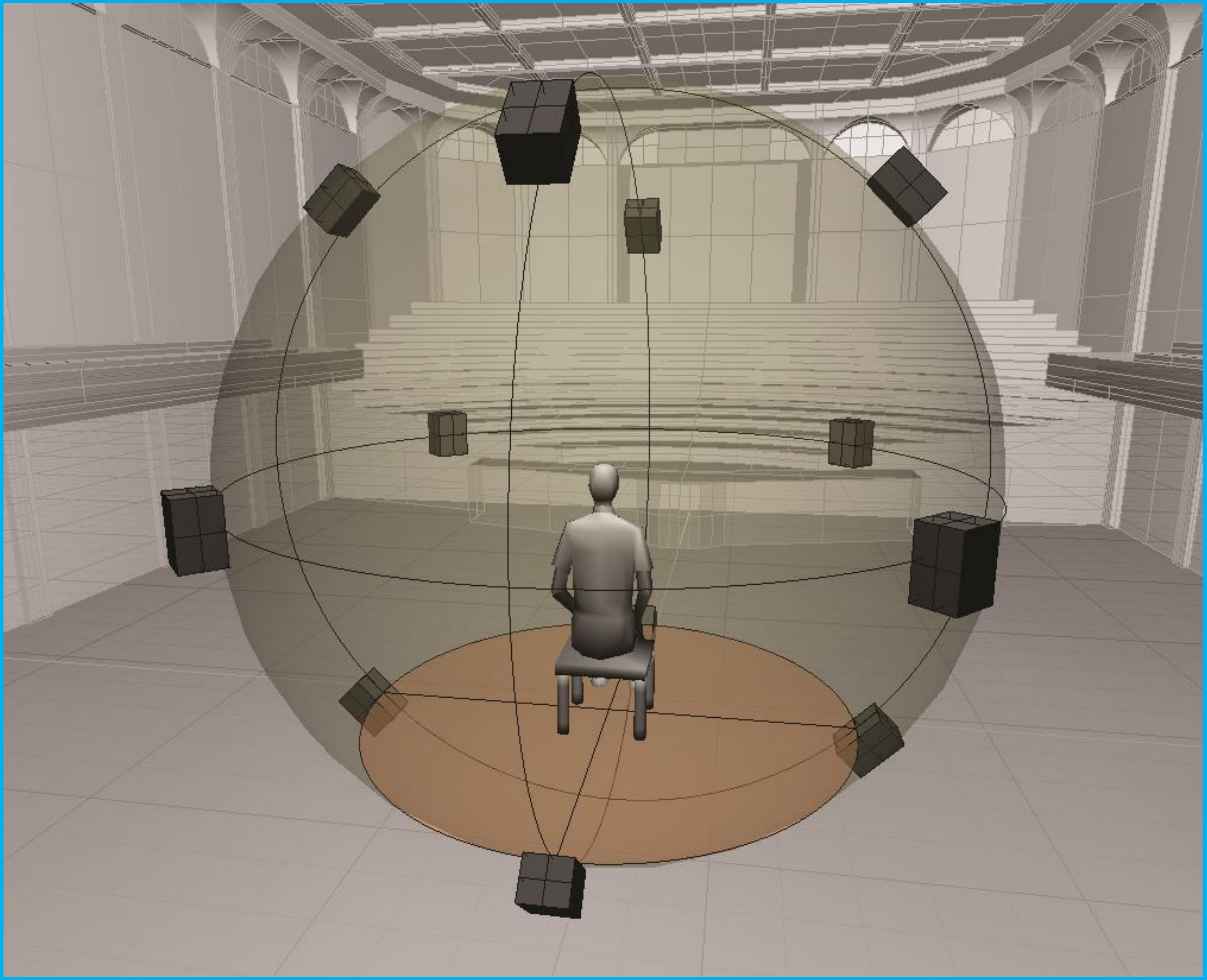
MOTU Audio I/O

(12) JBL 4326P + 4 subs

London BSS DSP

SoundLab - Software

Auralisation – Ambisonic



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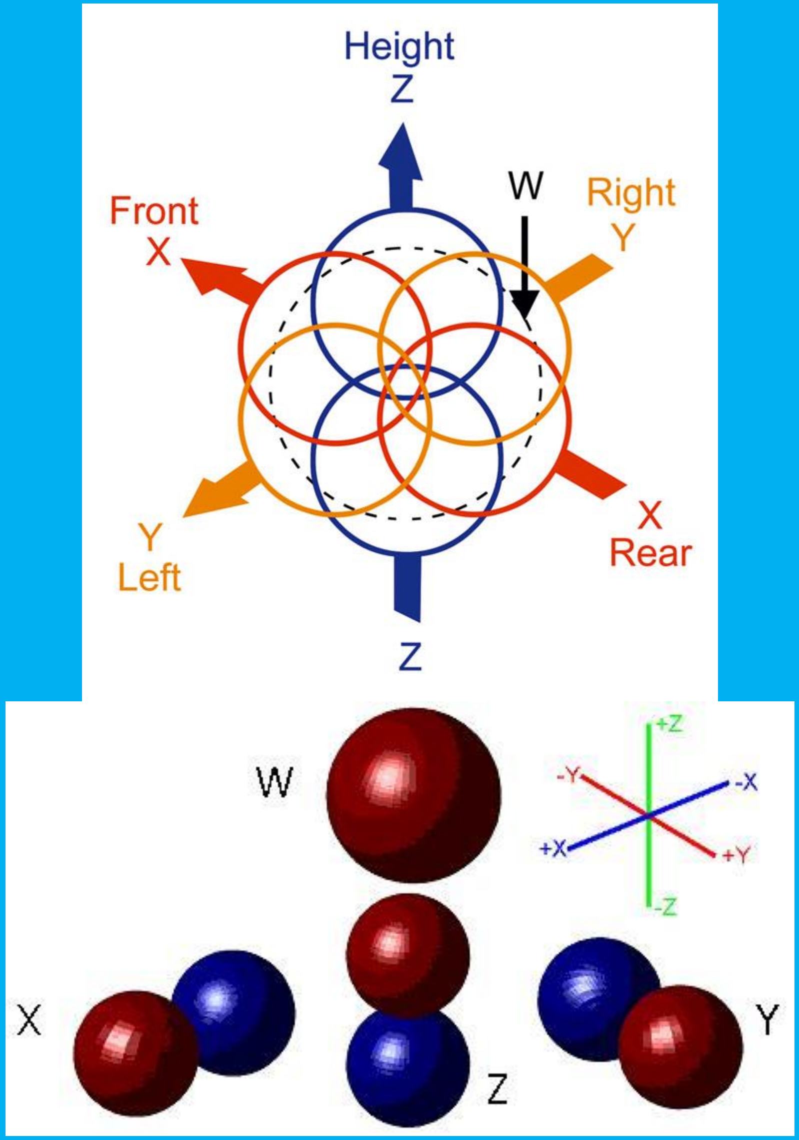
Auralisation – B-Format to Ambisonic



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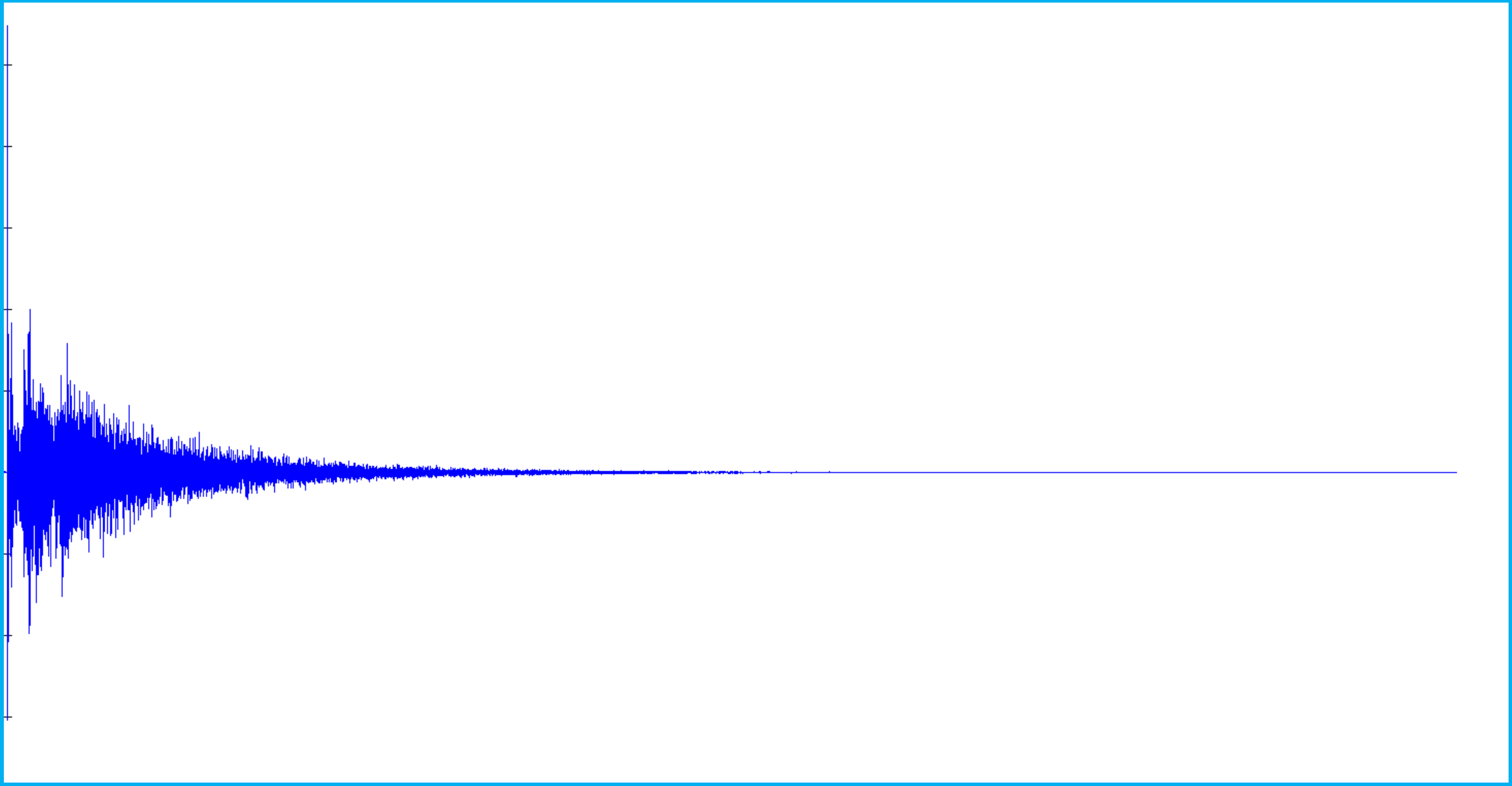
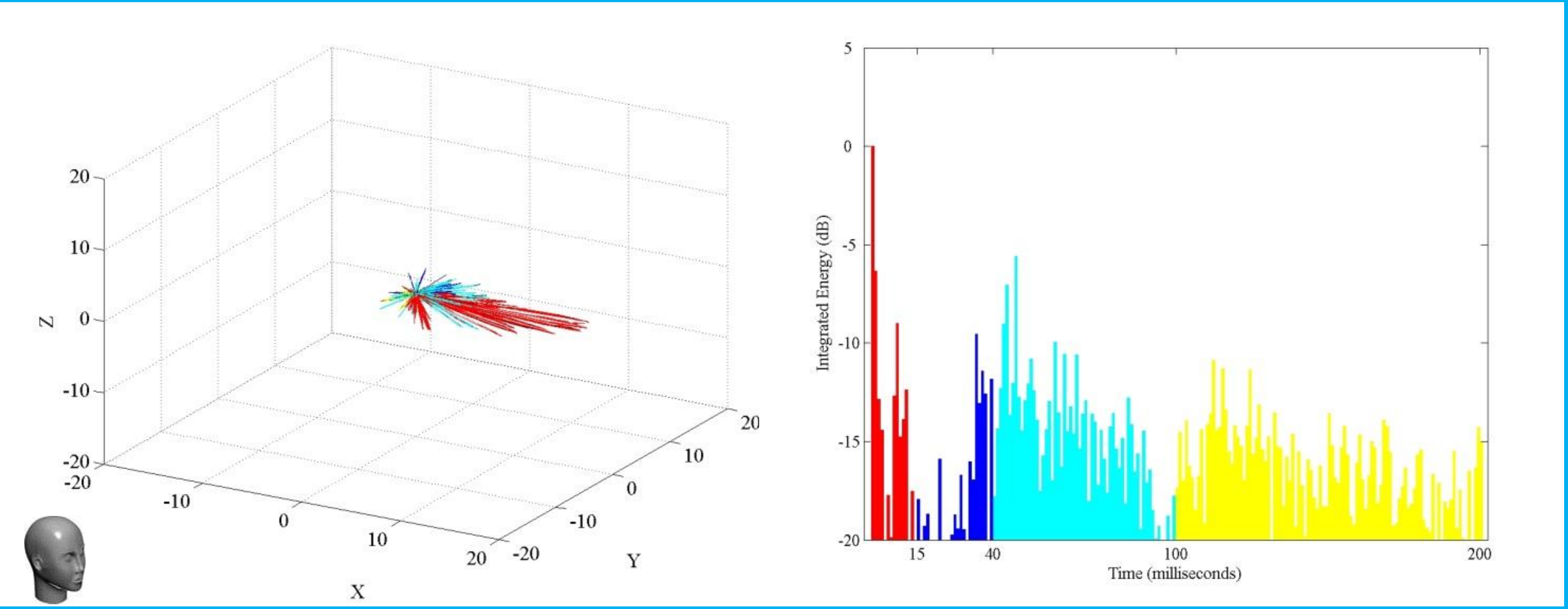
Time Information – 4 channel



Spatial Information – Very Frontal



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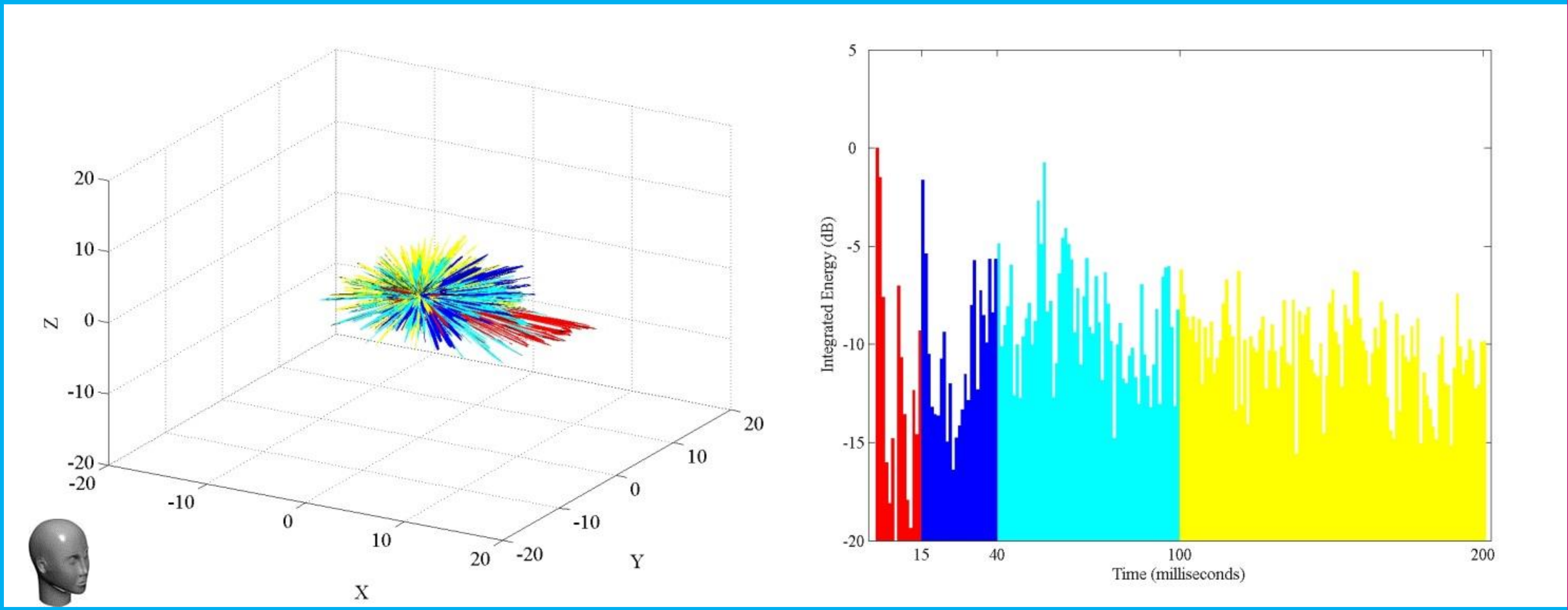
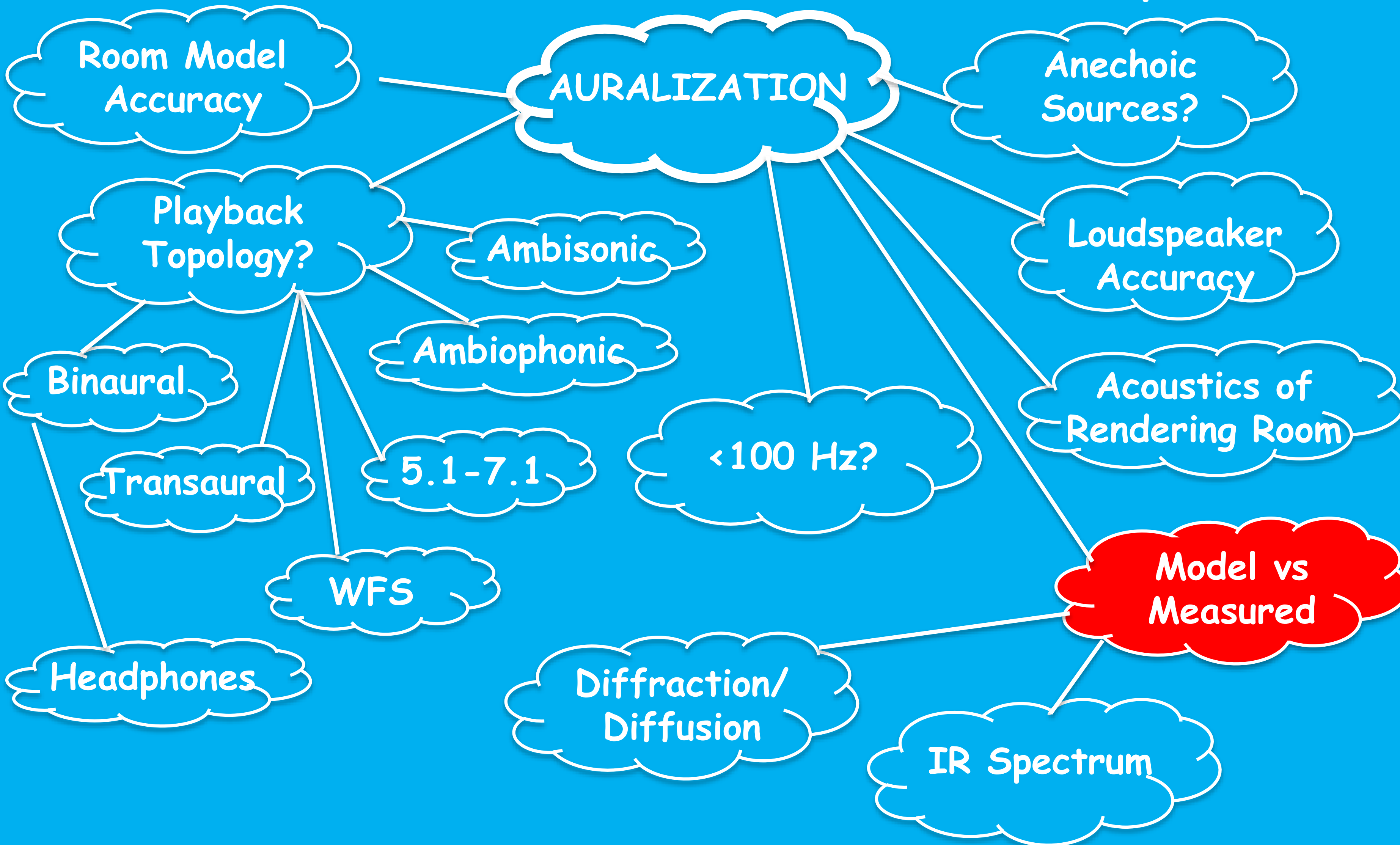
Spatial Information – Better Hall



Auralization – What Could Be Simpler?



Northrop - Original Hall

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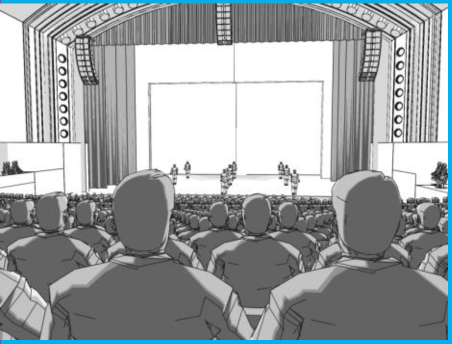
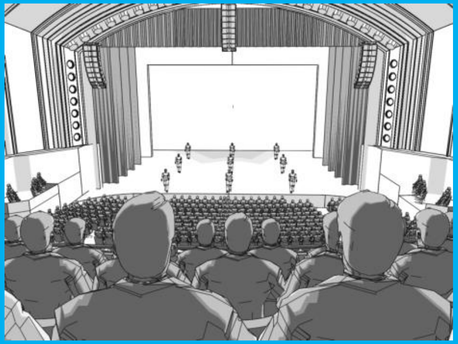
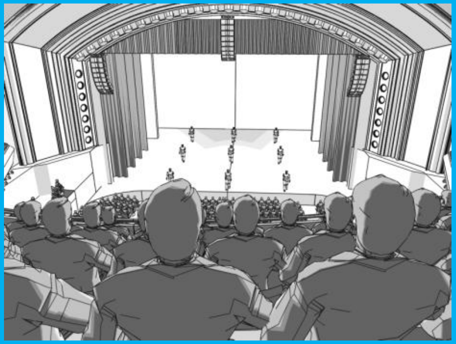
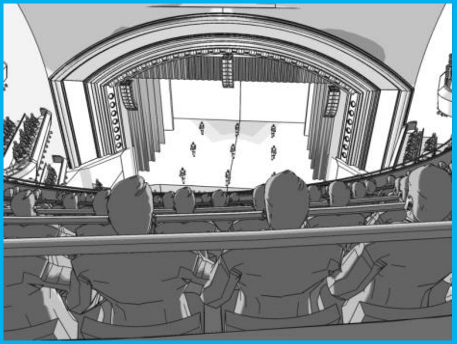
Northrop – Model at Close of DD

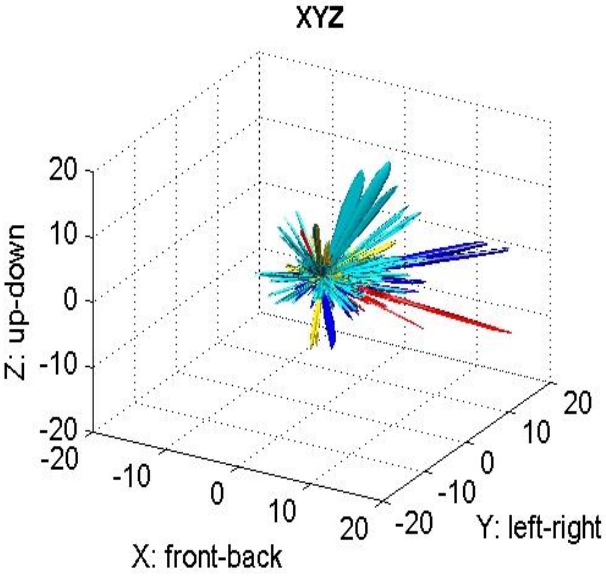


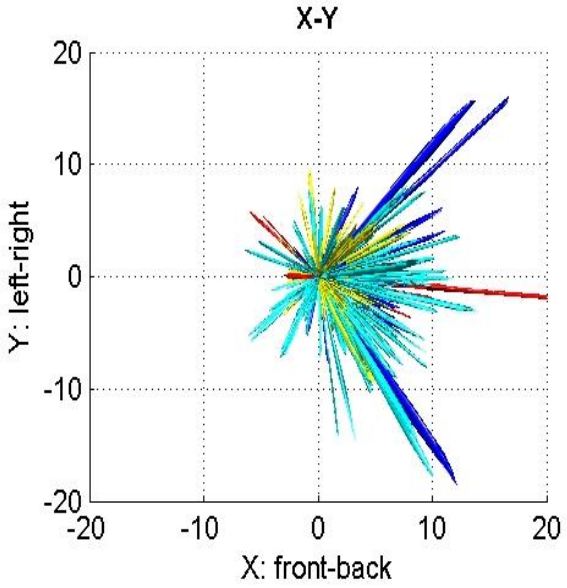




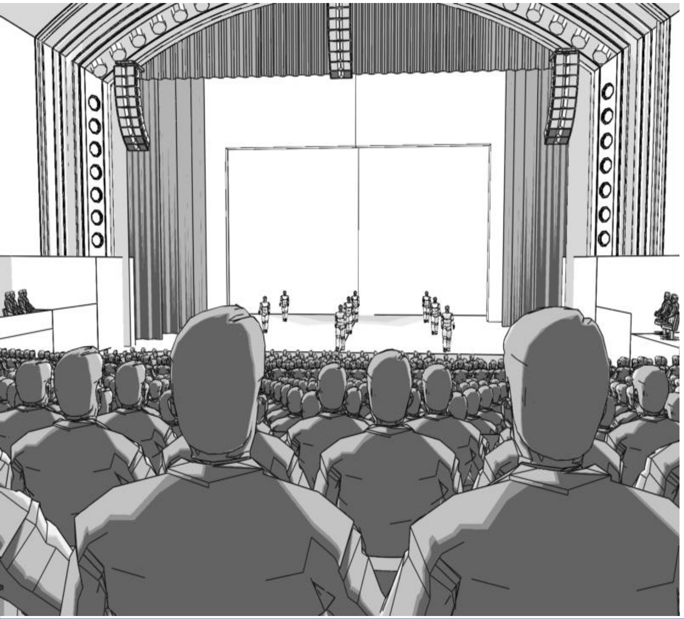


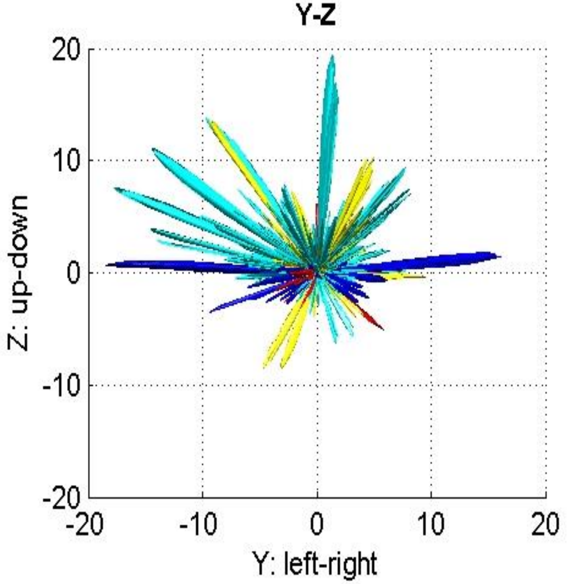
3D Audio Data Vis

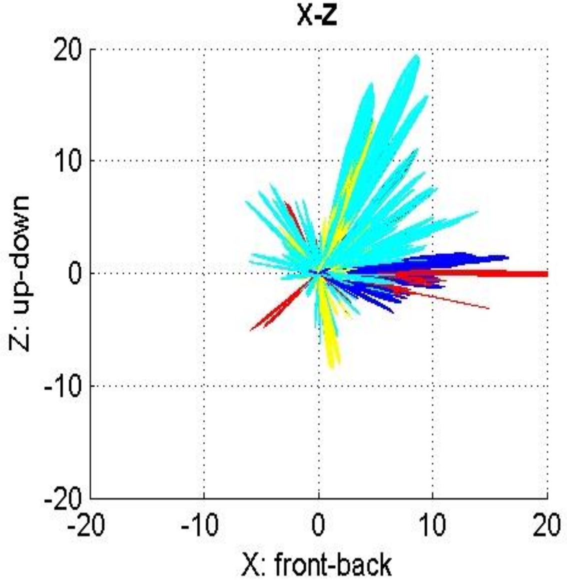




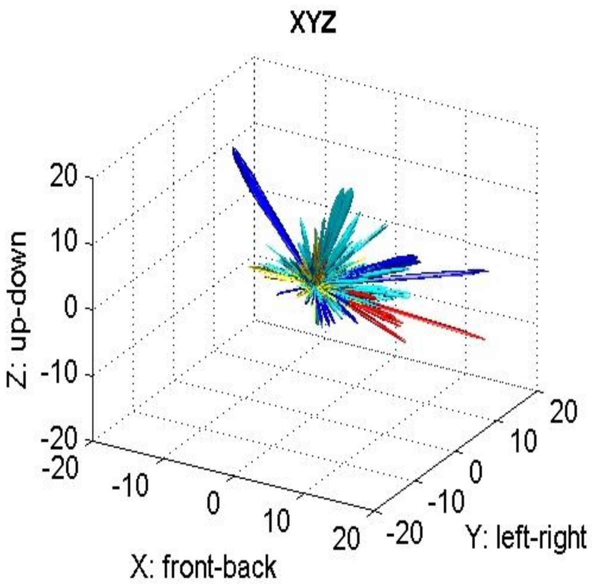
DD – Position 3

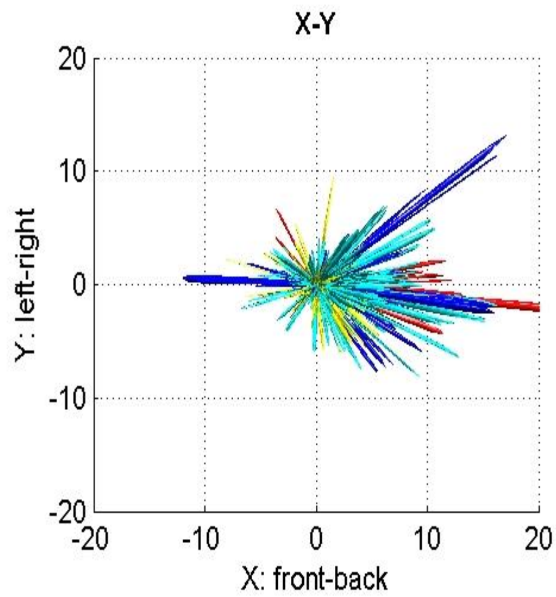




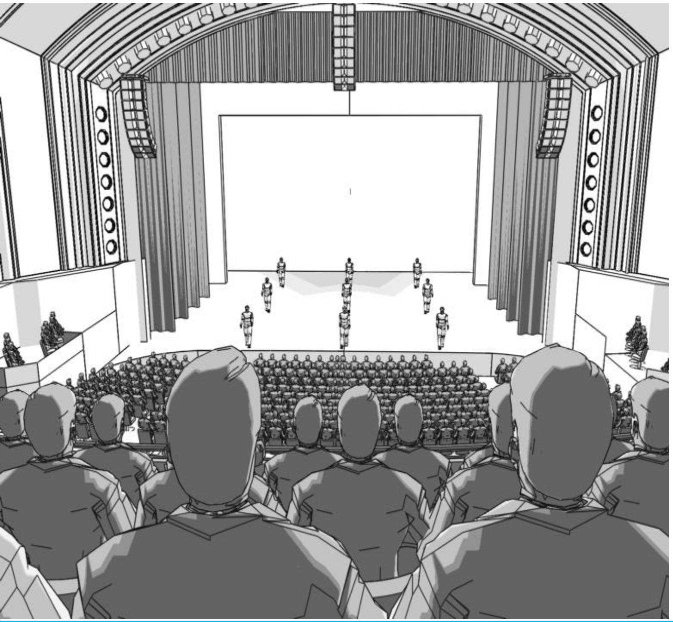


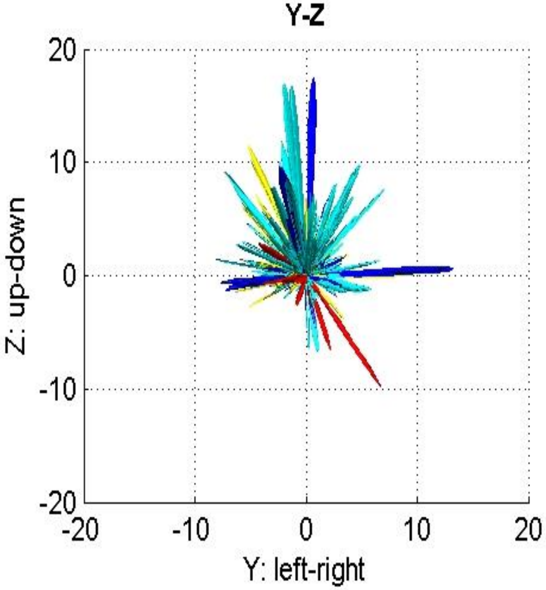
3D Audio Data Vis

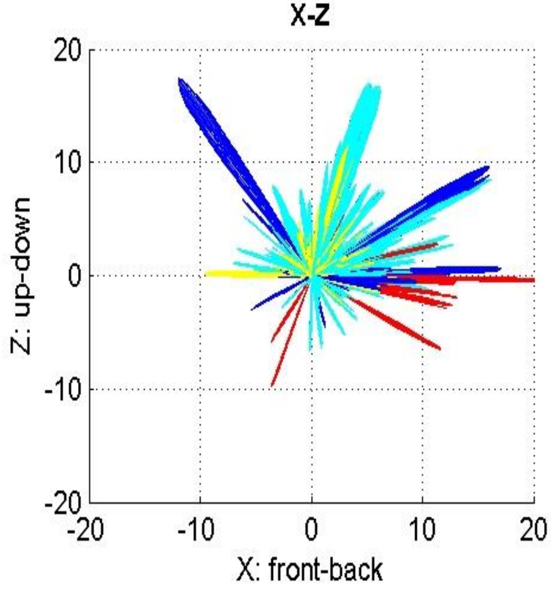




DD – Position 5







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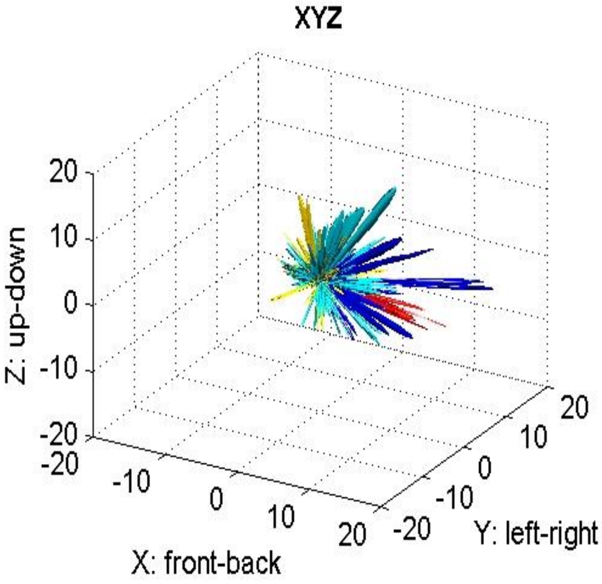
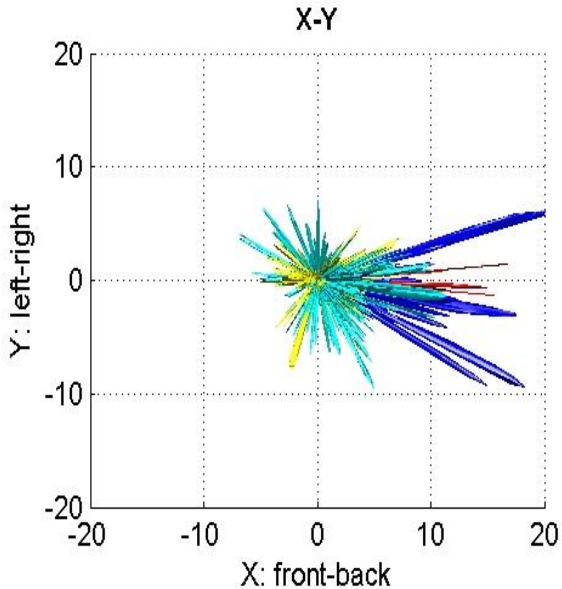
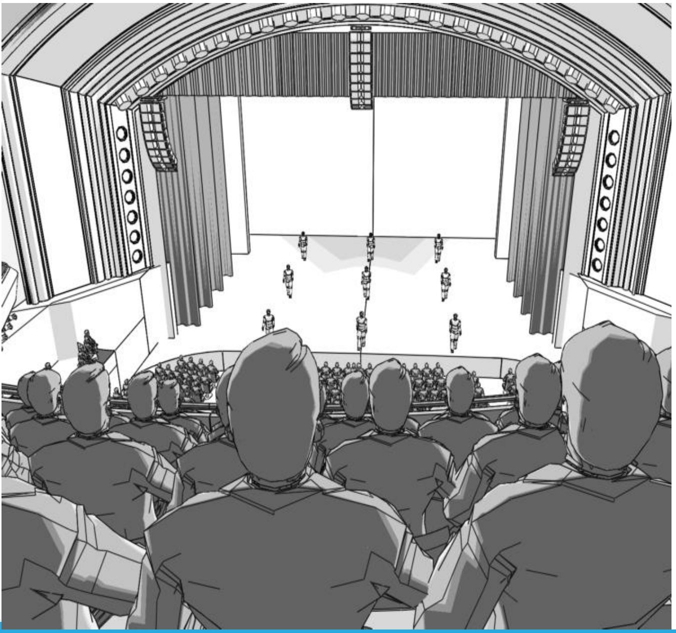
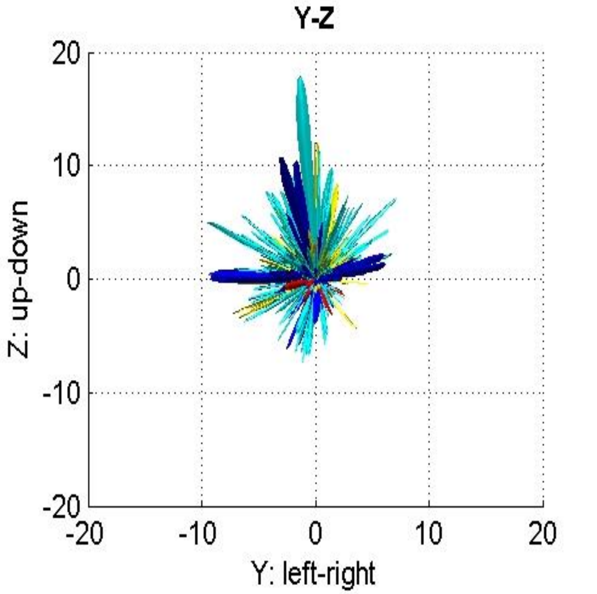
3D Audio Data Vis

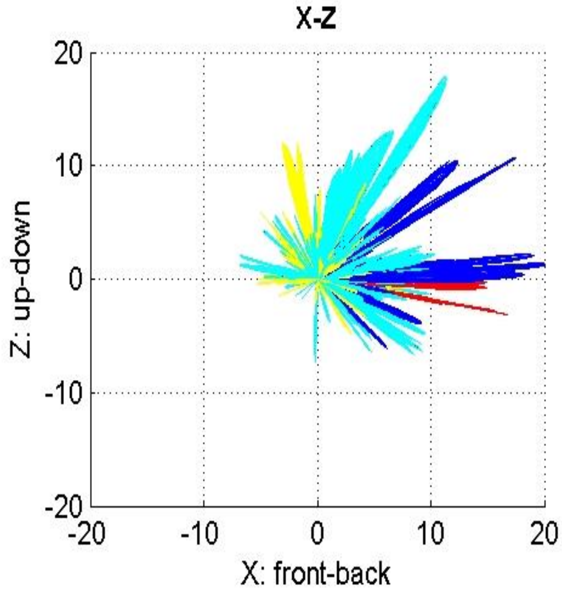




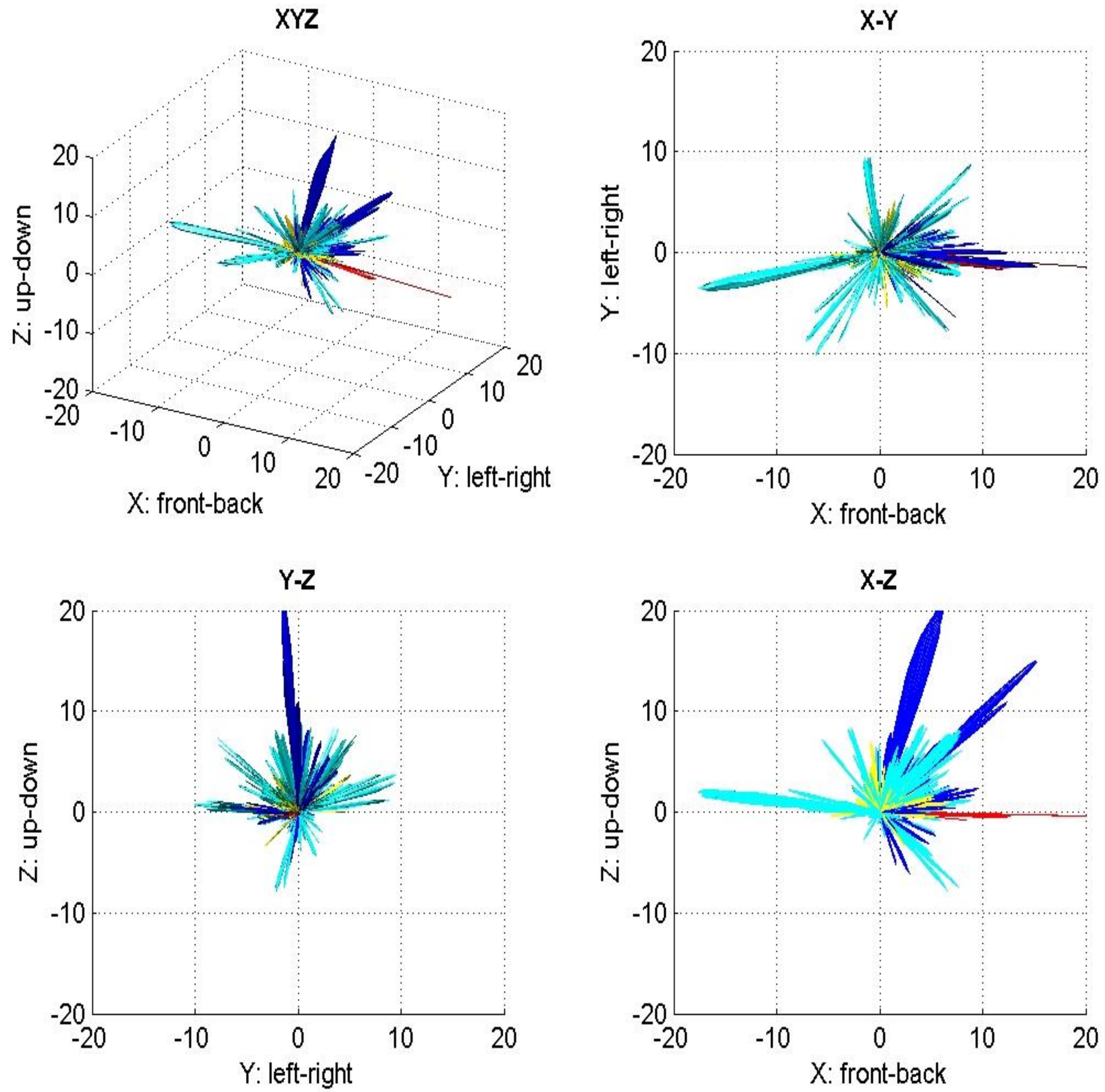
DD – Position 7



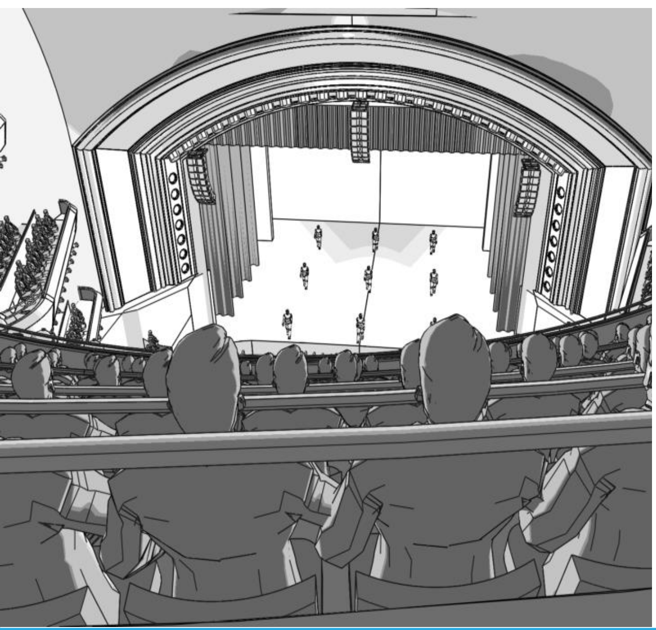




3D Audio Data Vis



DD – Position 9

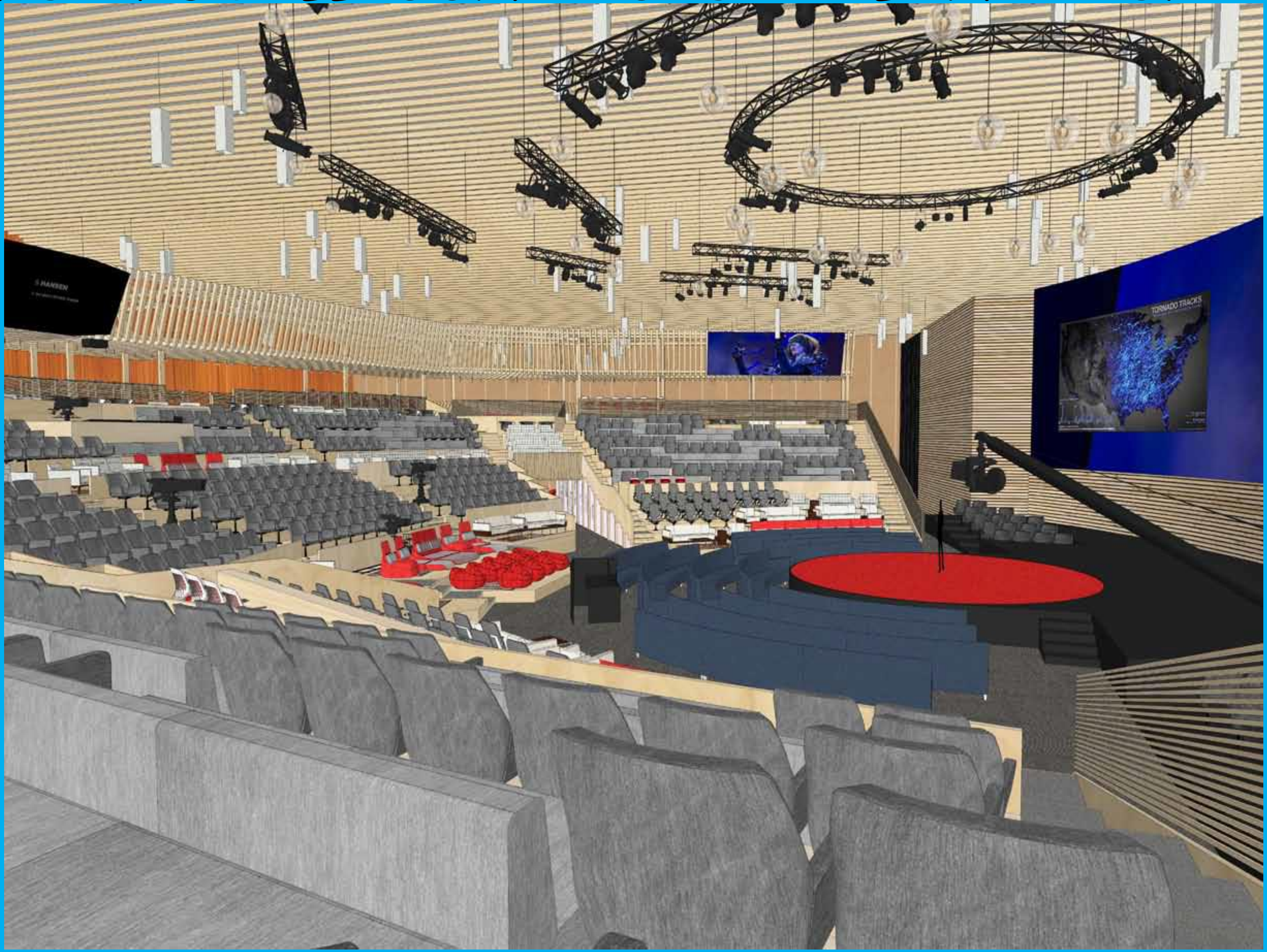


TED

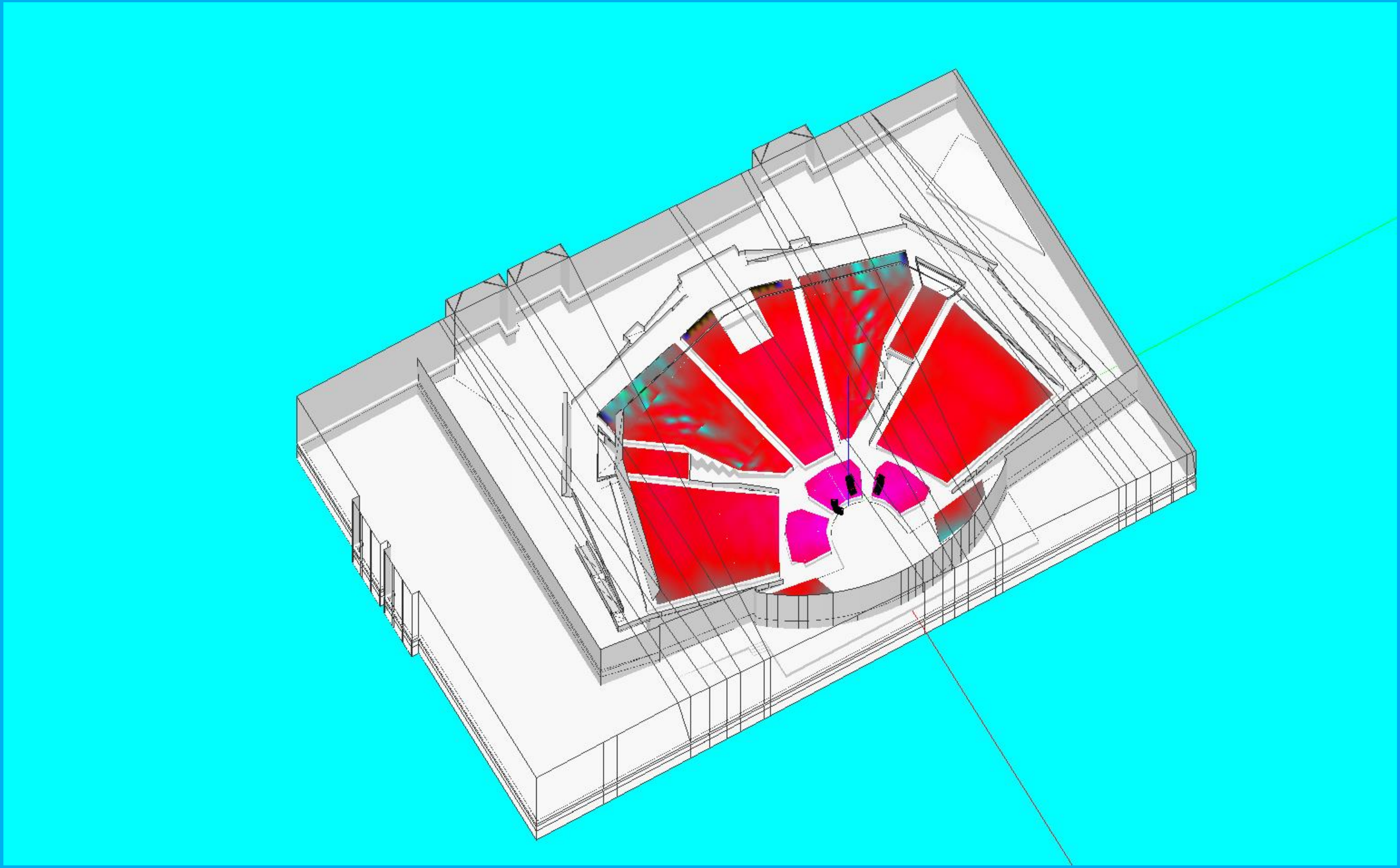
VANCOUVER CONVENTION CENTRE

BALLROOM THEATRE ● SOUNDLAB AURALIZATION

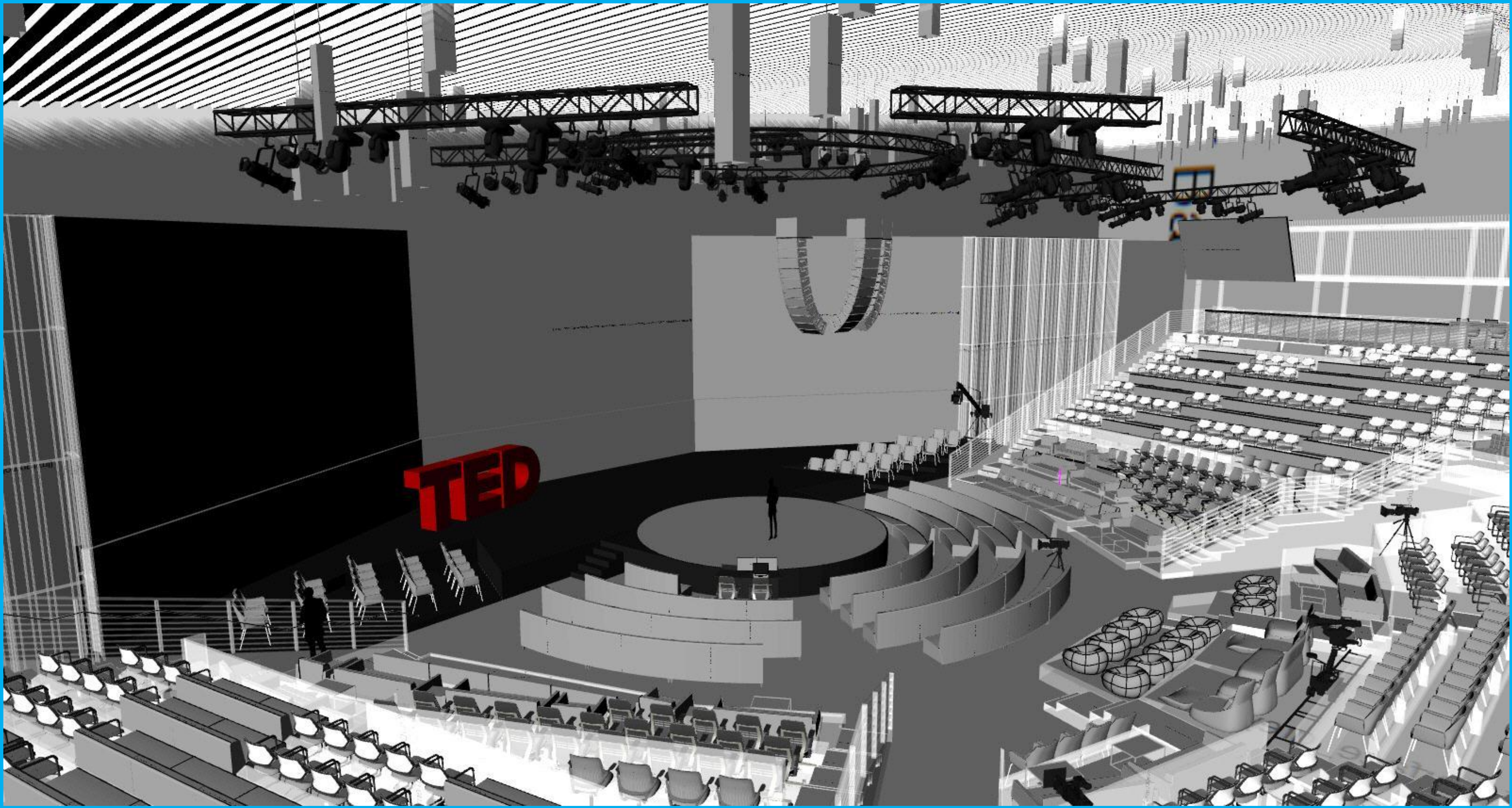
ADD THEATRE "SET" WITHIN ACOUSTICS OF EXISTING BALLROOM: ACOUSTICAL IMPACTS?



NEW STAGE/SEATING "SET" INSIDE BALLROOM

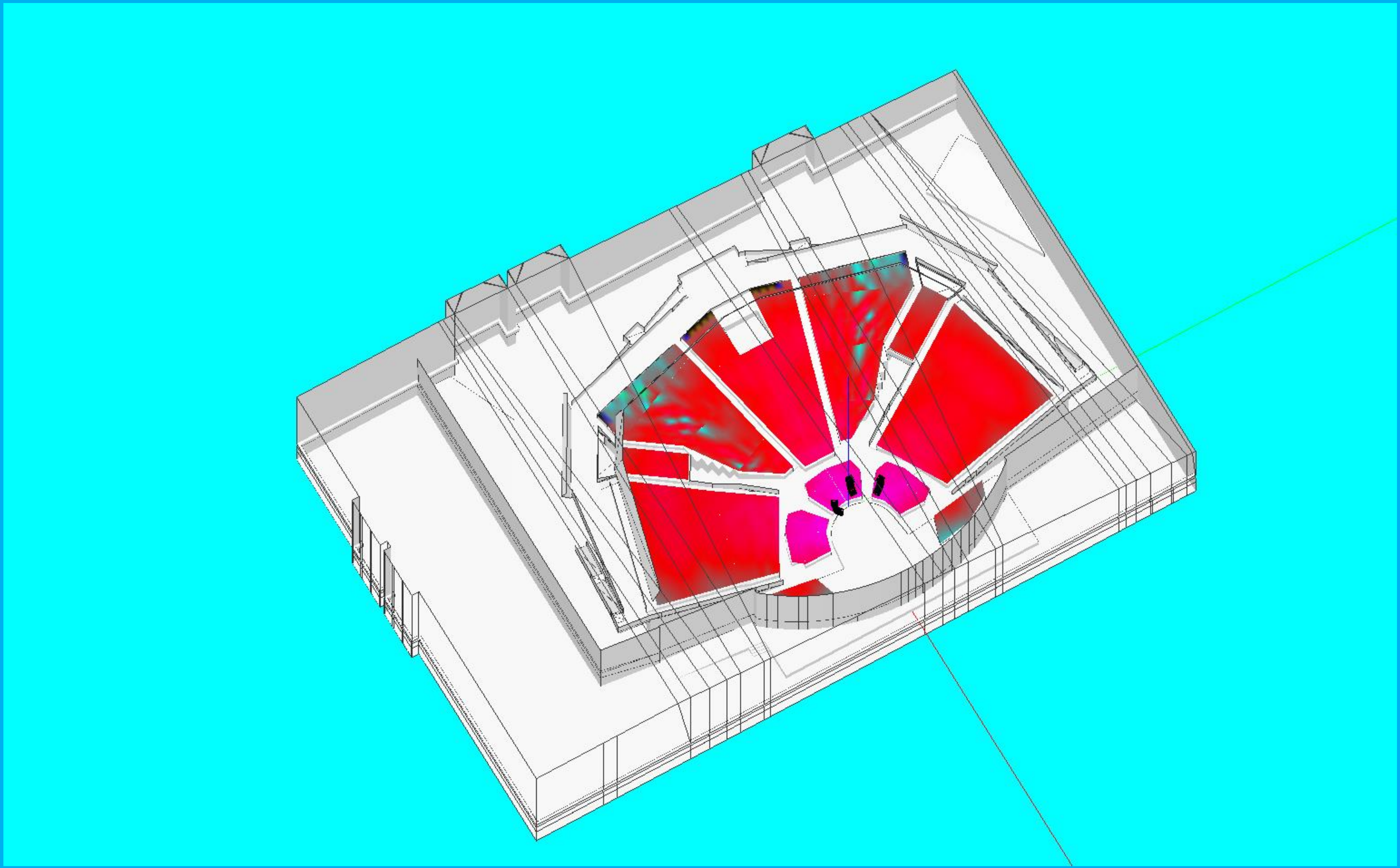


PERFORMANCE AUDIO SYSTEM DESIGN

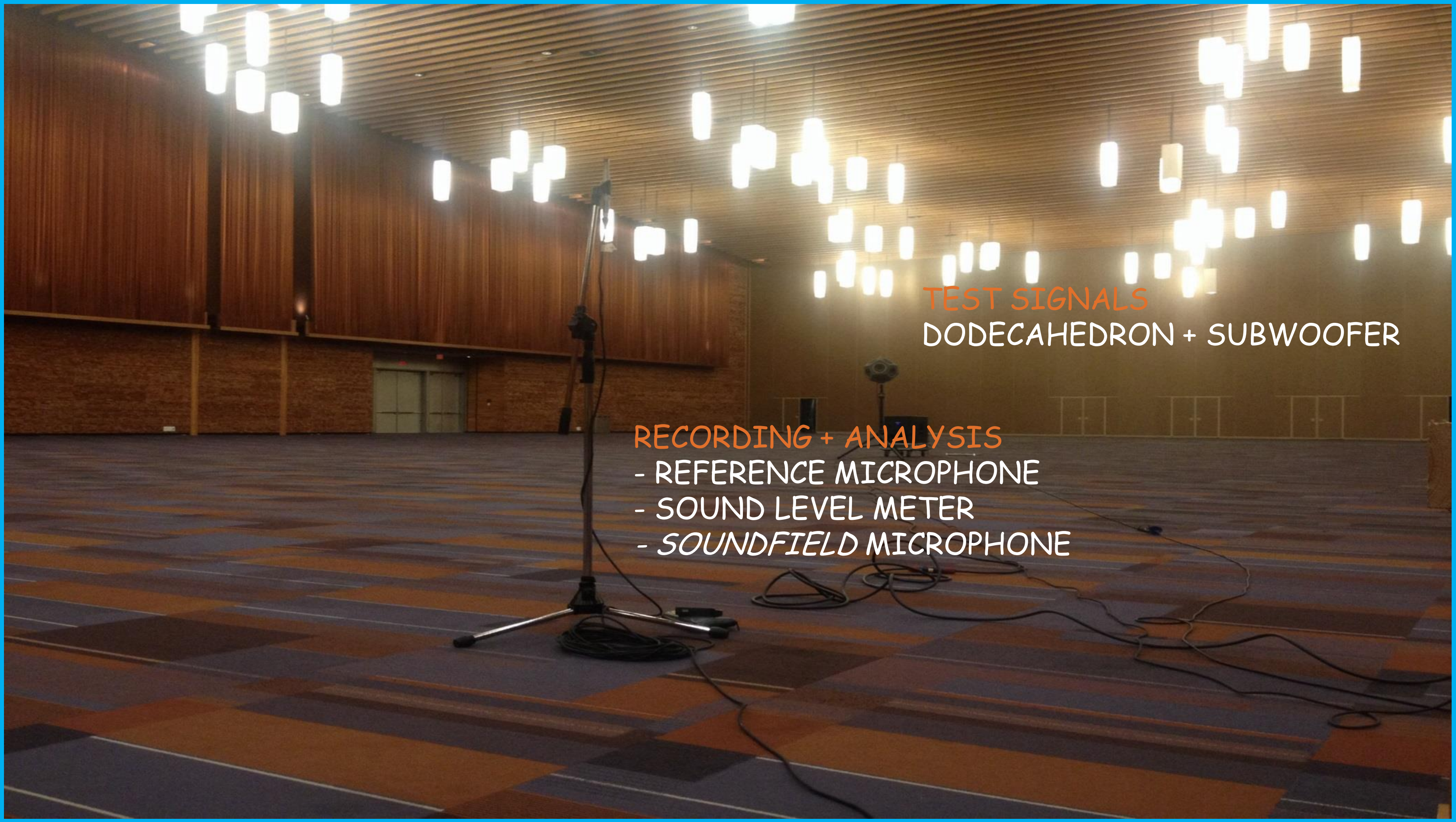


ARUP

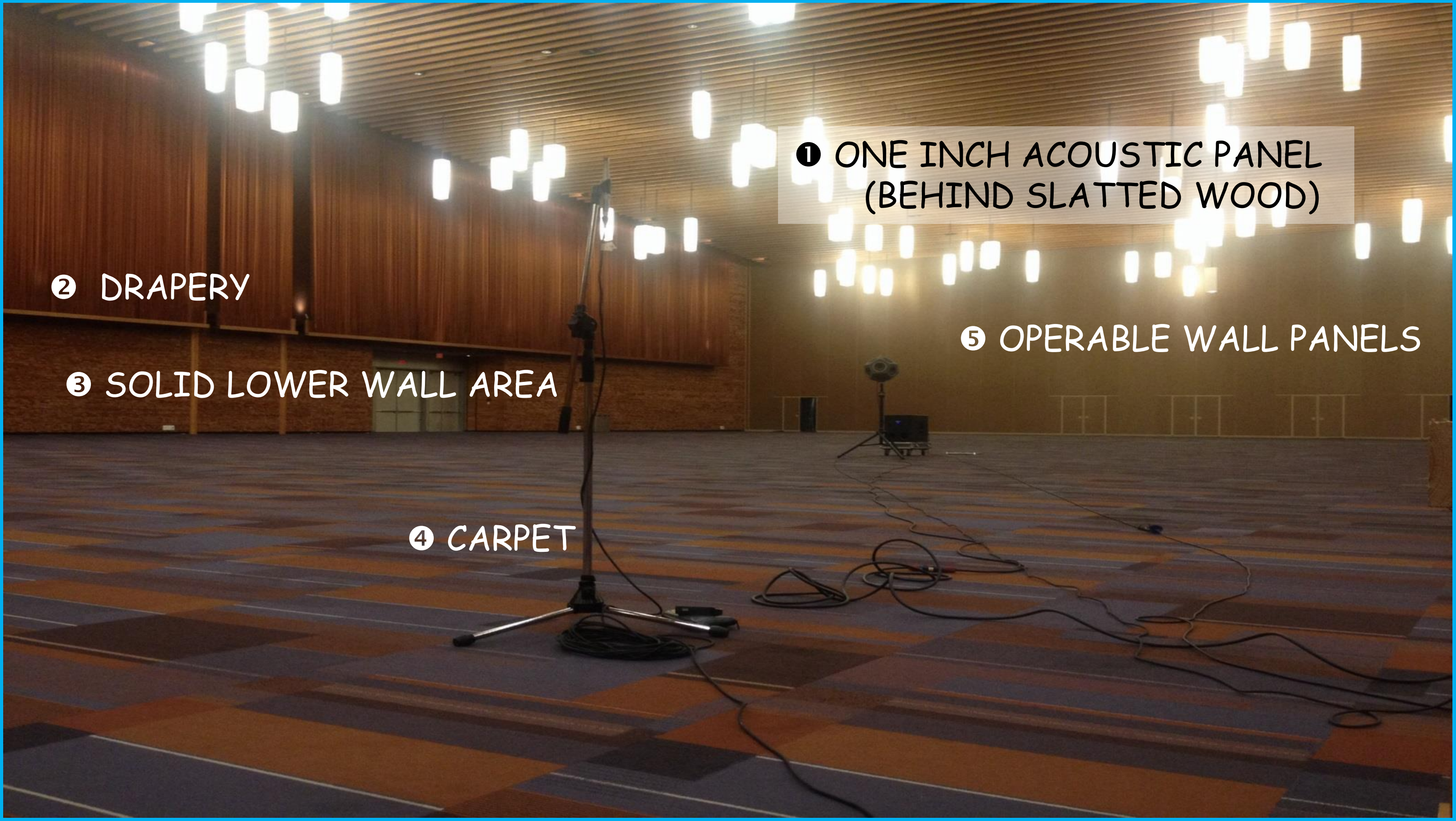
COVERAGE FOR ALL SEATING FROM MAIN ARRAY



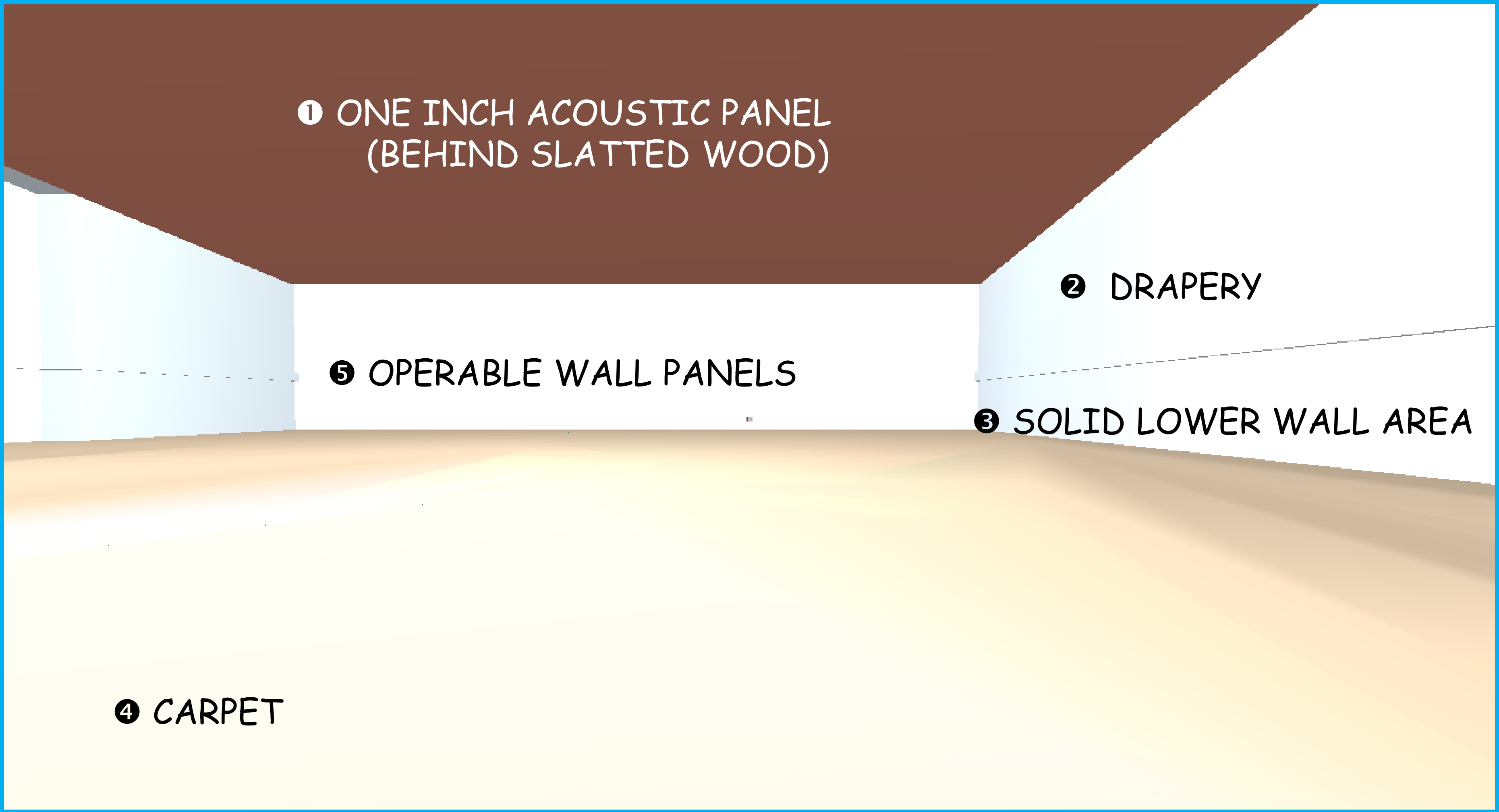
SITE ACOUSTIC TESTING



CALIBRATE MODEL TO SITE MEASUREMENTS

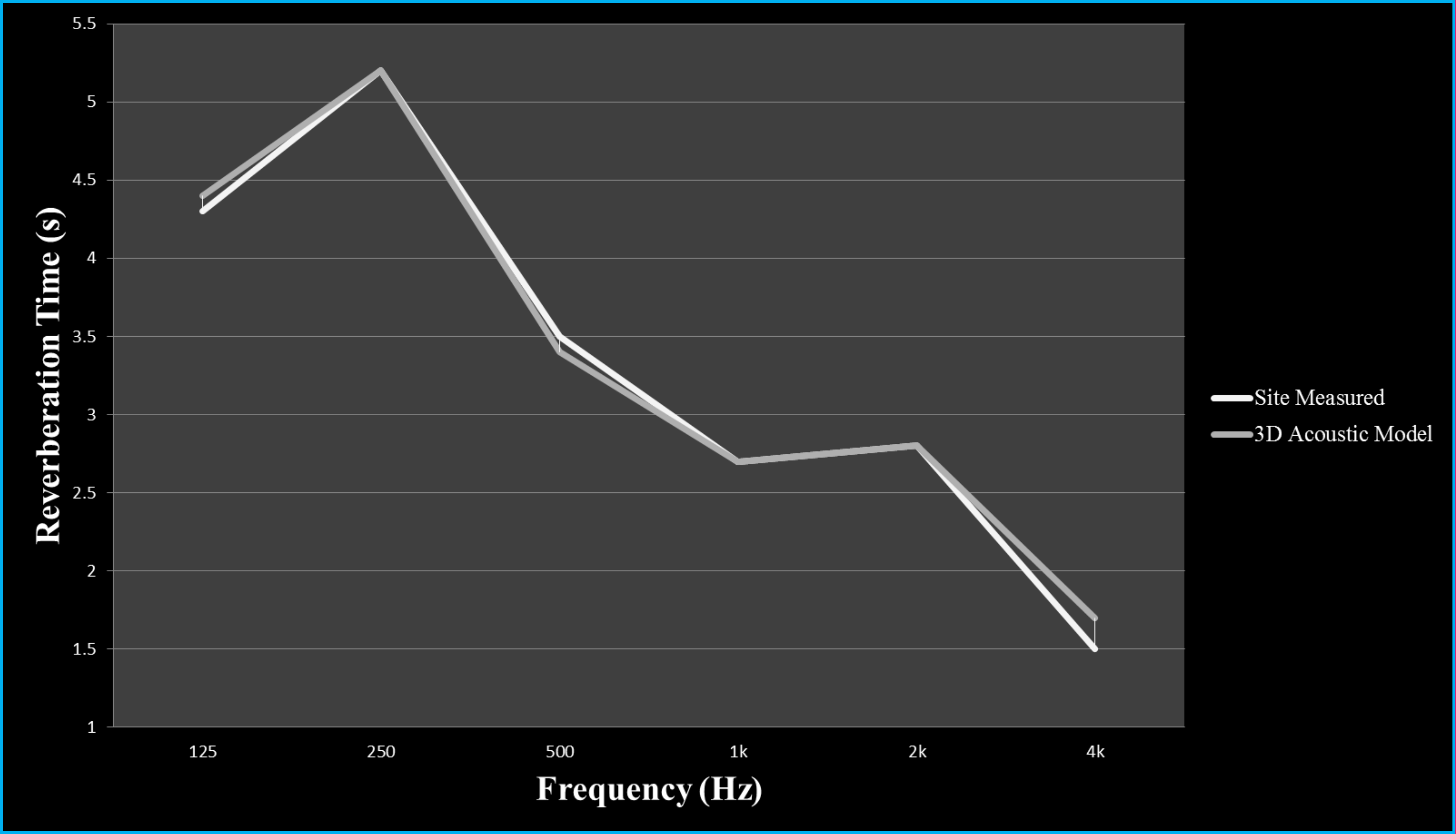


CALIBRATE BALLROOM ACOUSTIC MODEL TO SITE MEASUREMENTS



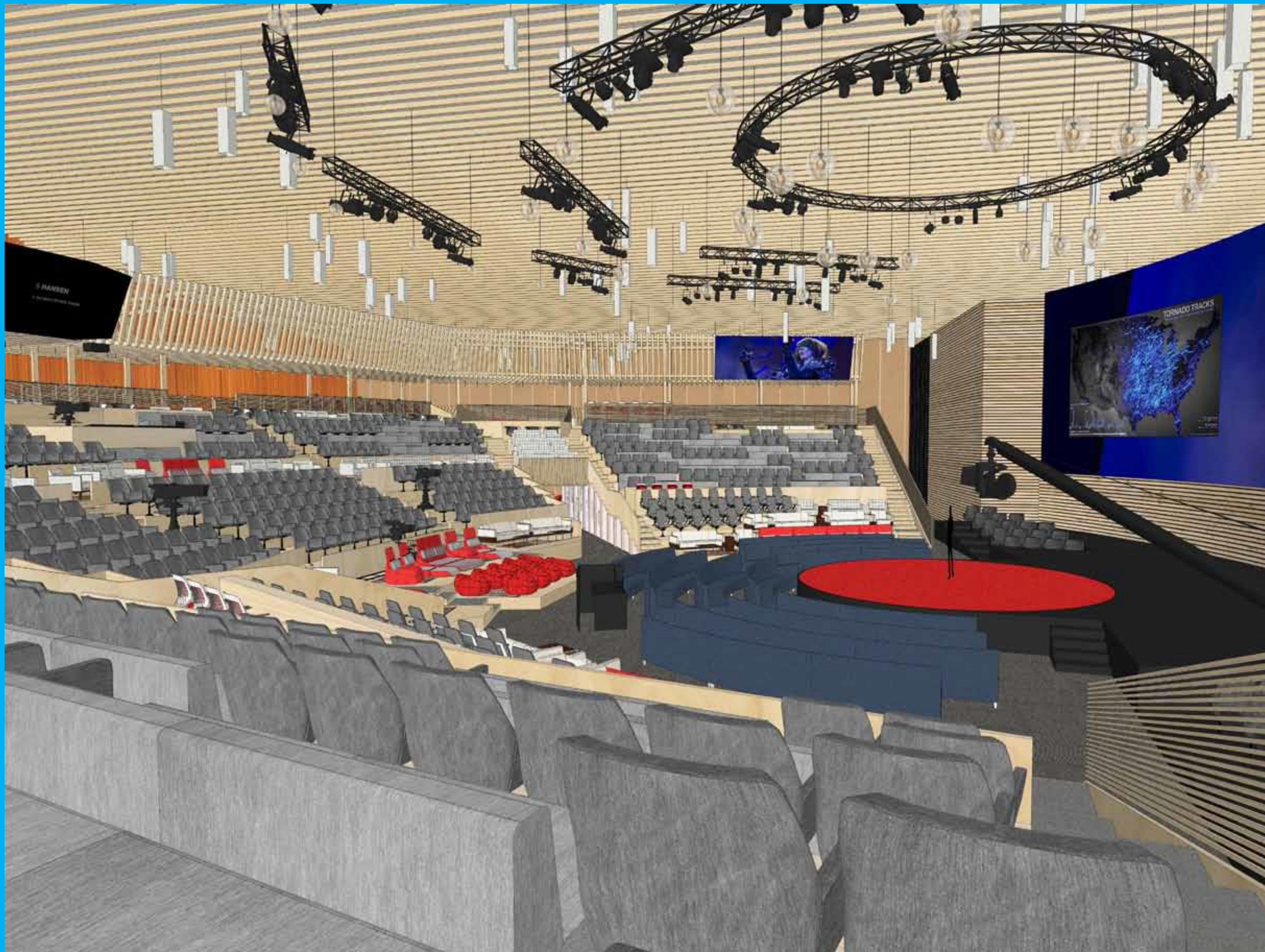
ARUP

CALIBRATE BALLROOM ACOUSTIC MODEL TO SITE MEASUREMENTS

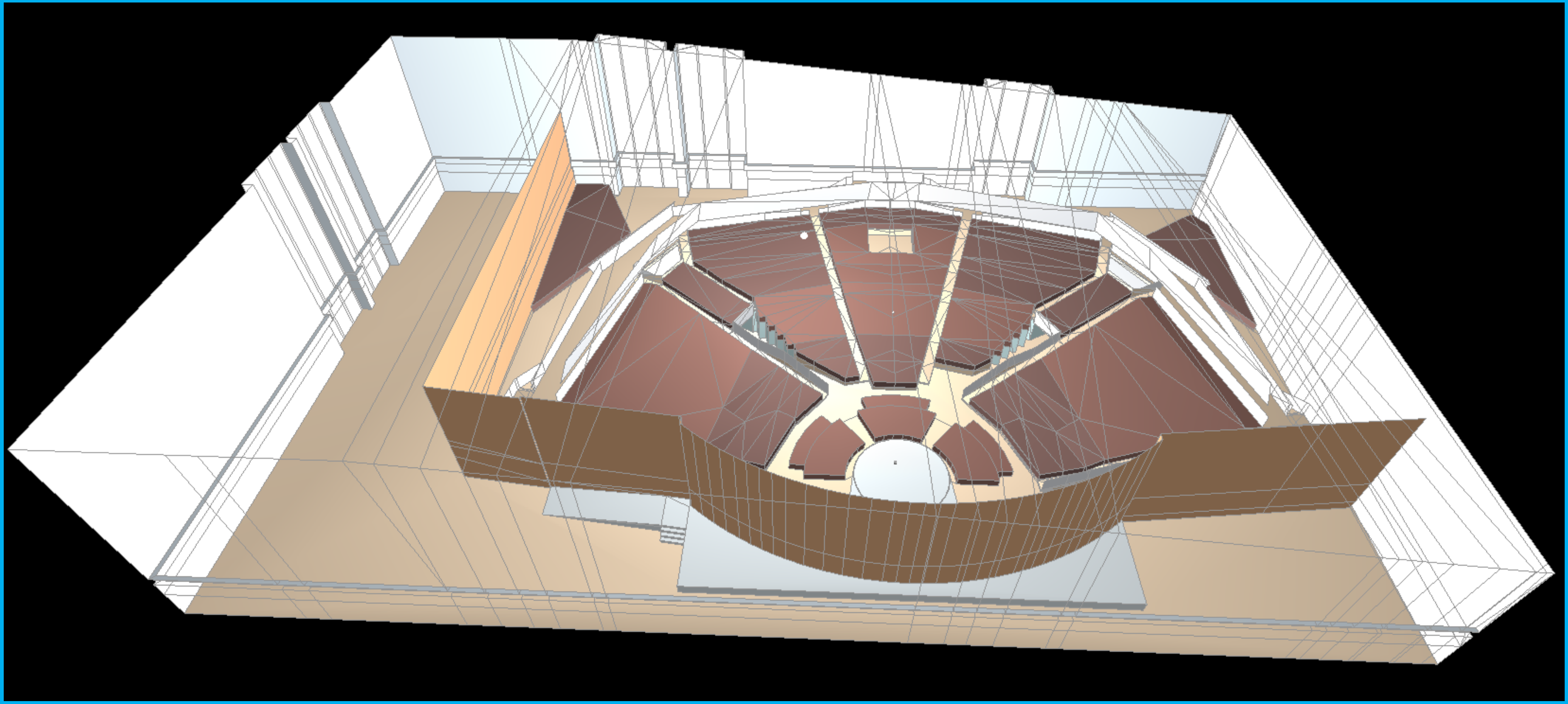


ARUP

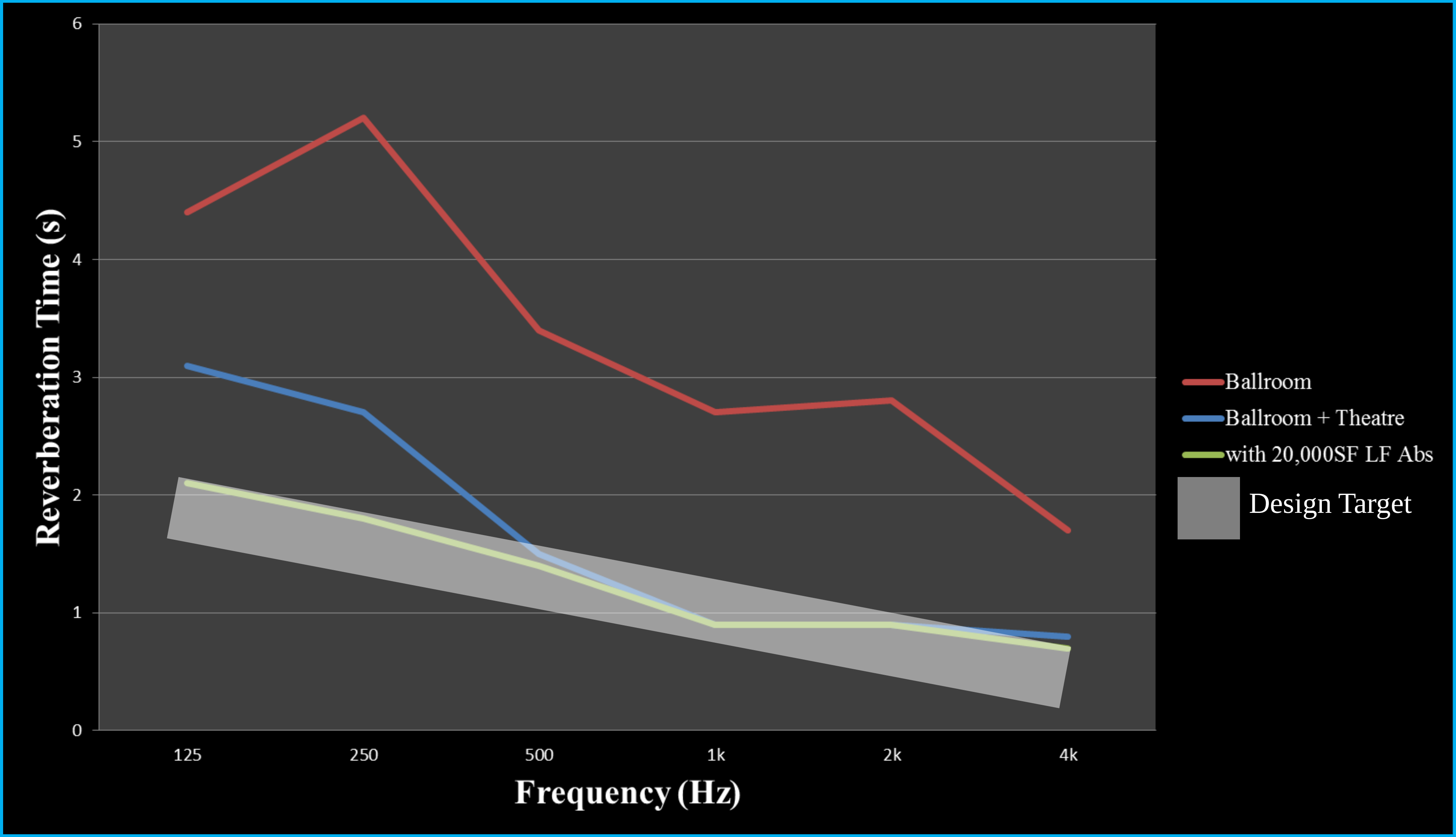
ADD THEATRE TO BALLROOM ACOUSTIC MODEL



COMPLETED ROOM ACOUSTIC MODEL

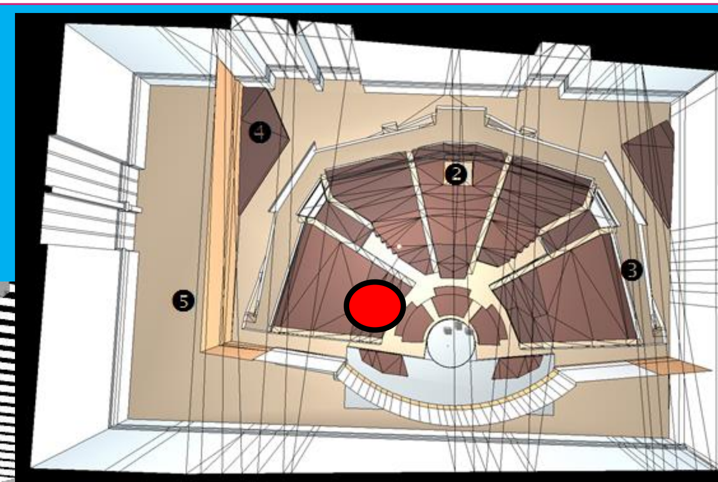


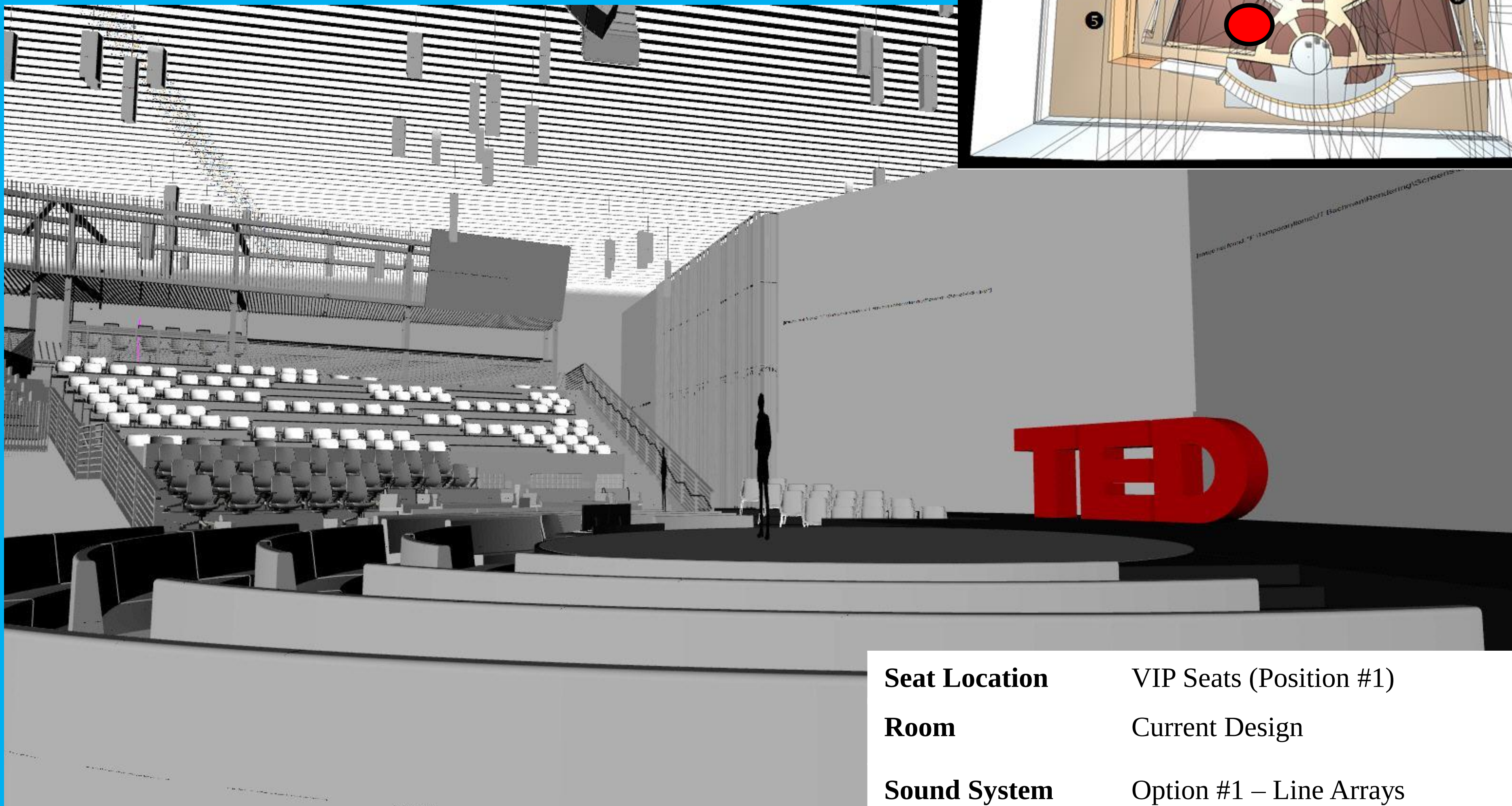
CALIBRATE BALLROOM ACOUSTIC MODEL TO SITE MEASUREMENTS



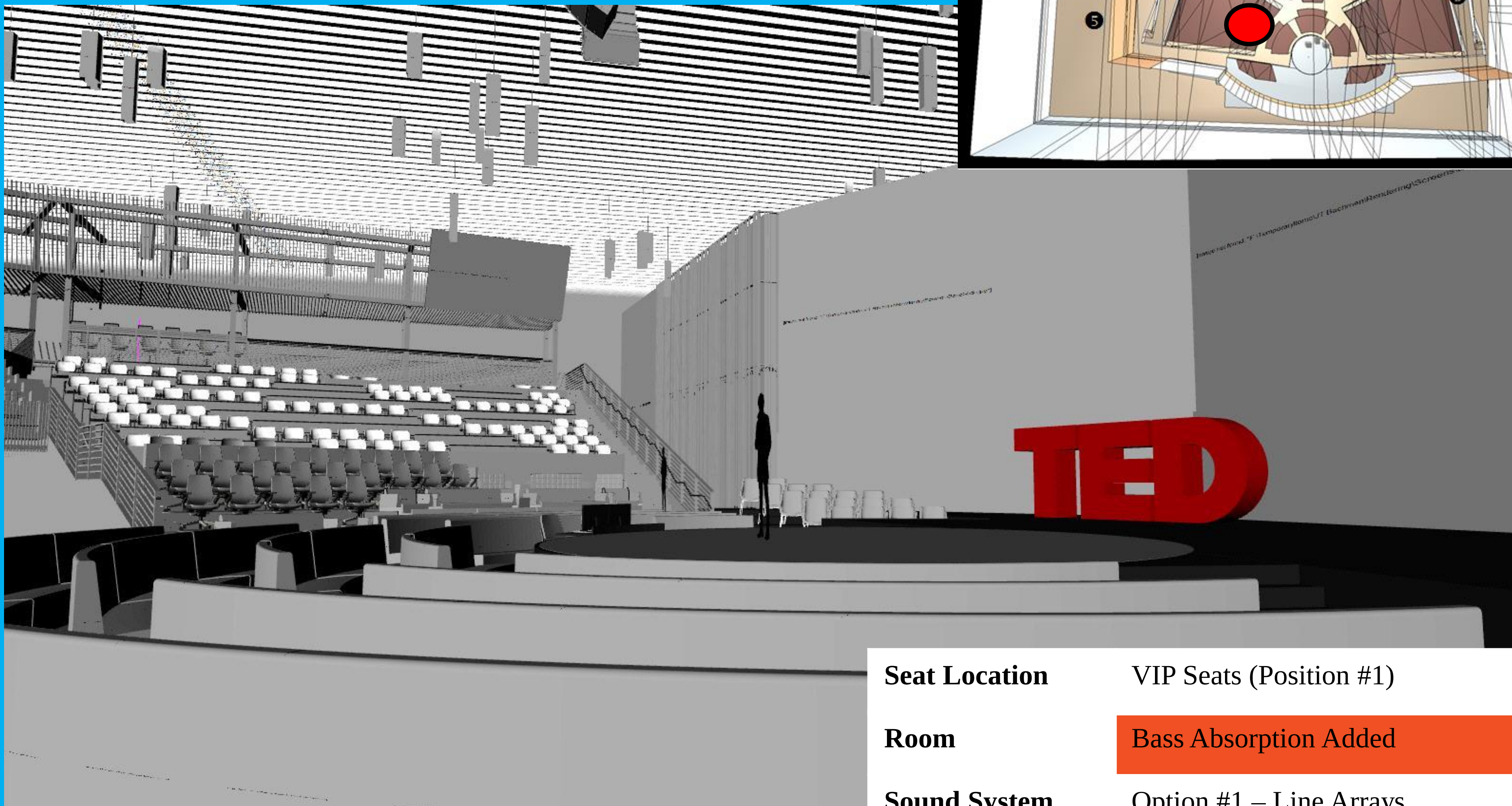
ARUP

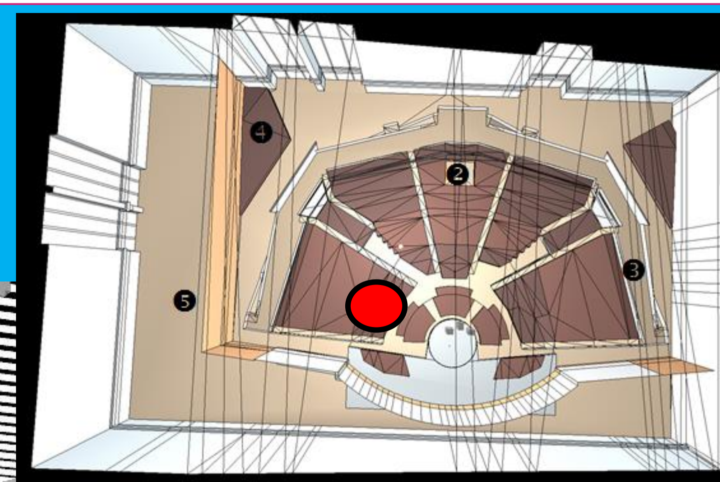
LISTENING POSITIONS





Seat Location	VIP Seats (Position #1)
Room	Current Design
Sound System	Option #1 – Line Arrays





Seat Location	VIP Seats (Position #1)
Room	Bass Absorption Added
Sound System	Option #1 – Line Arrays

THE END....THANK YOU....