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Euronoise 2018 Crete

The Significance of Sound Diffraction Effects in Ancient Theatres: Measurements & Simulations, With and without Audience

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P.E. MEDITERRANEAN ACOUSTICS RESEARCH & DEVELOPMENT **(PEMARD), CYPRUS**

INTRO & CONTENTS

INTRO

A Theatre is as space which has to fulfill 2 basic requirements.

1. Audience should be able to SEE and HEAR clearly events on stage.
2. To achieve that one places audience as close as practically possible at minimum distances.
3. Ancient Greeks used common sense and placed the audience at equal distances from the stage at elevated circles.
4. They positioned theatres on slopes far away from the sound masking effects of the sea and the trees.
5. In my mind there is nothing magical about ancient theatre acoustics.
6. However, since this shape lasted the test of natural selection, it must possess certain advantages which we examine.
7. In particular here we examine the significance of Sound Diffraction in Greek-Roman theatres, with and without audience.
8. To do this we use Wave Based Geometrical Acoustics to highlight the effects of sound Diffraction.

CONTENTS

PART 1 – PREVIOUS WORK: MEASUREMENTS WITHOUT AUDIENCE

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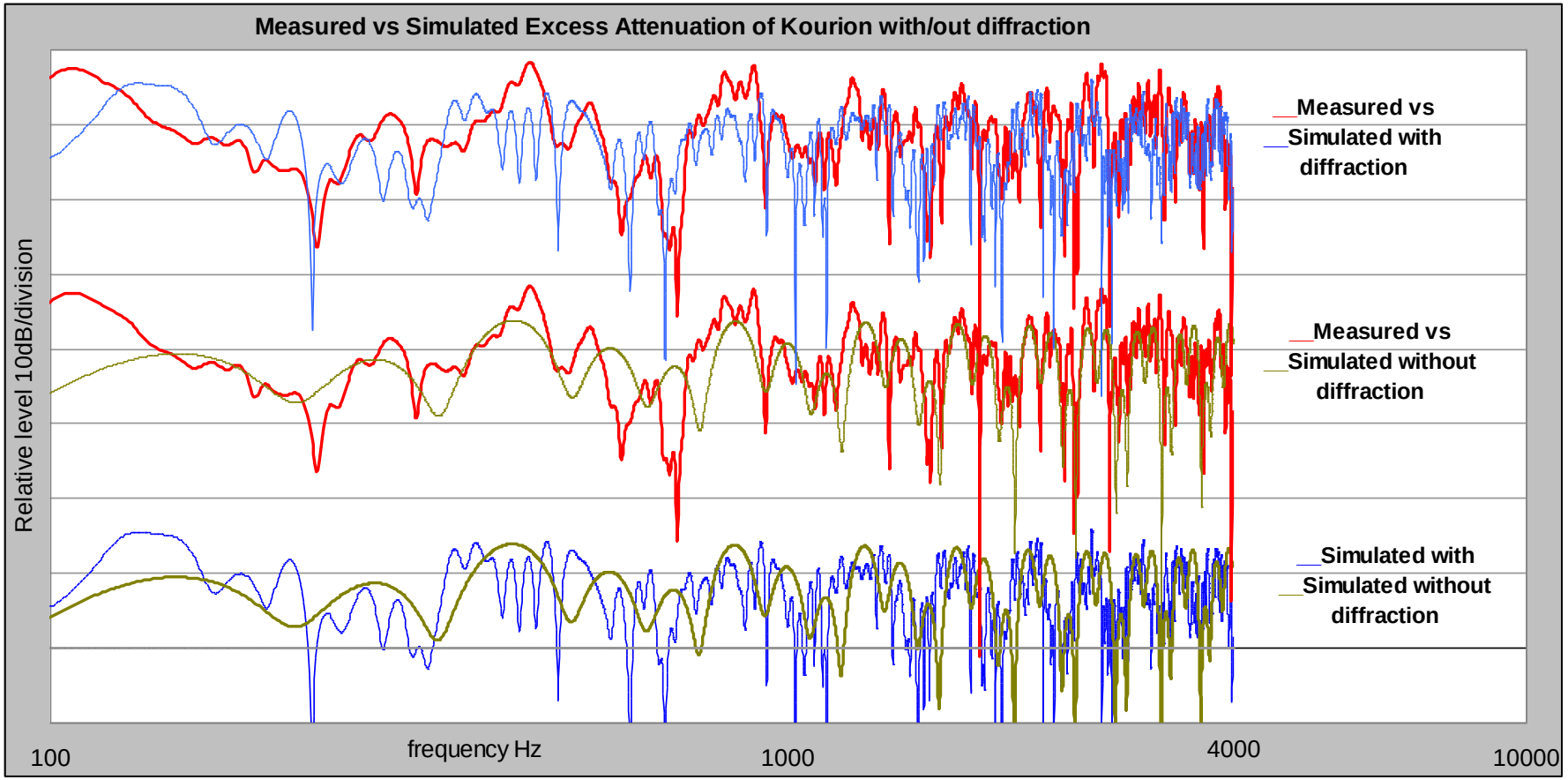
From our previous paper*, a picture of Kourion Ancient Theatre in Cyprus

*"The Significance of Diffraction in Ancient Theatres" 2011

PART 1 – PREVIOUS WORK: MEASUREMENTS WITHOUT AUDIENCE

The effect of Diffraction: Simulations with/out Diffraction vs Measurements

*"The Significance of Diffraction in Ancient Theatres", 2011



PART 2 – WAVE BASED GEOMETRICAL ACOUSTICS (WBGA)

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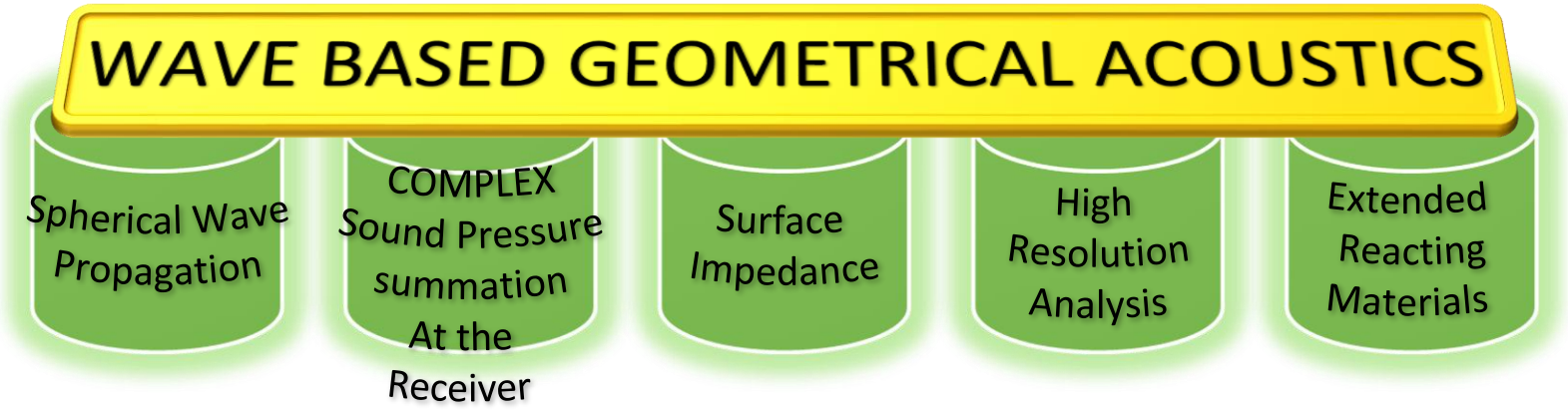
What is Wave Based Geometrical Acoustics (WBGA)?

It is the method by which the calculation of acoustical fields takes into account the principle of superposition, using both amplitude and phase thus producing interference phenomena.

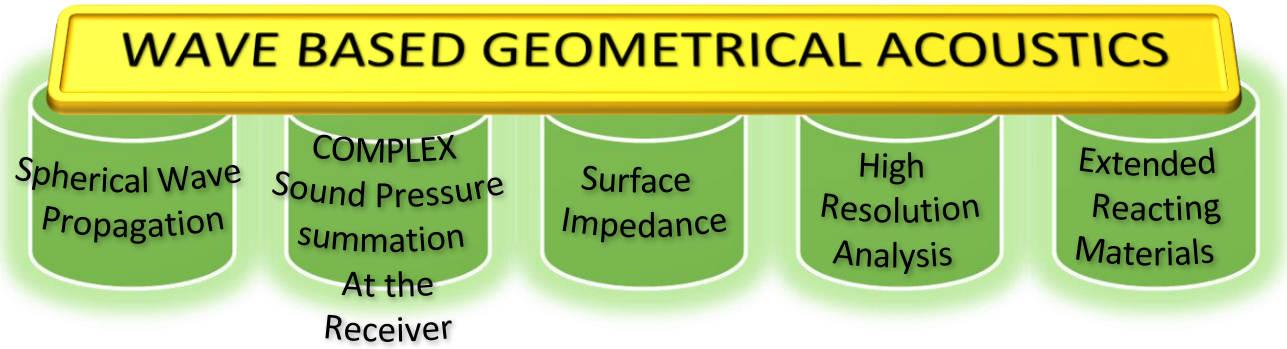
Below **some** of the pillars of the WBGA method:



PART 2 – WAVE BASED GEOMETRICAL ACOUSTICS (WBGA)

WBGA allows for:

- Edge diffractions &
- finite sized object reflections
- refraction and more.
- By using **spherical wave angle depended extended reacting surface impedance,**
- we get complex pressures,
- and phase,
- in high resolution frequency analysis,
- producing interference phenomena.



PART 2 – WAVE BASED GEOMETRICAL ACOUSTICS (WBGA)

The term Wave Based Geometrical Acoustics (WBGA), was first coined by Yiu Lam in his 2005 paper "Issues for computer modelling of room acoustics in non-concert hall settings".

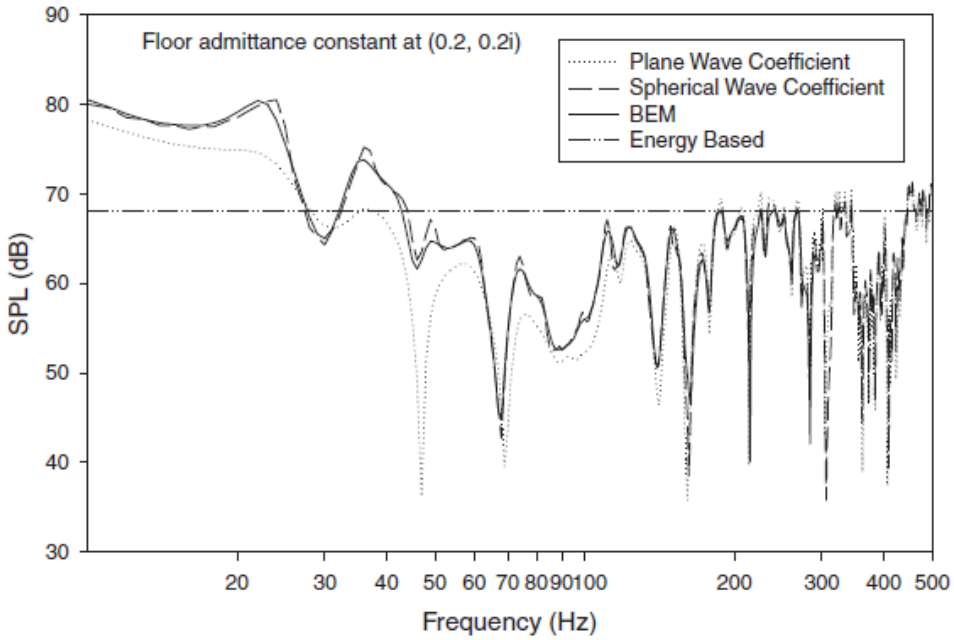


Fig. 9 Comparison of wave based room acoustics models for predicting complex sound field in the standard listening room for the frequency range from 10 to 500 Hz with an assumed frequency independent absorptive admittance value of $(0.2, 0.2i)$ for the floor.

Acoust. Sci. & Tech. **26**, 2 (2005)

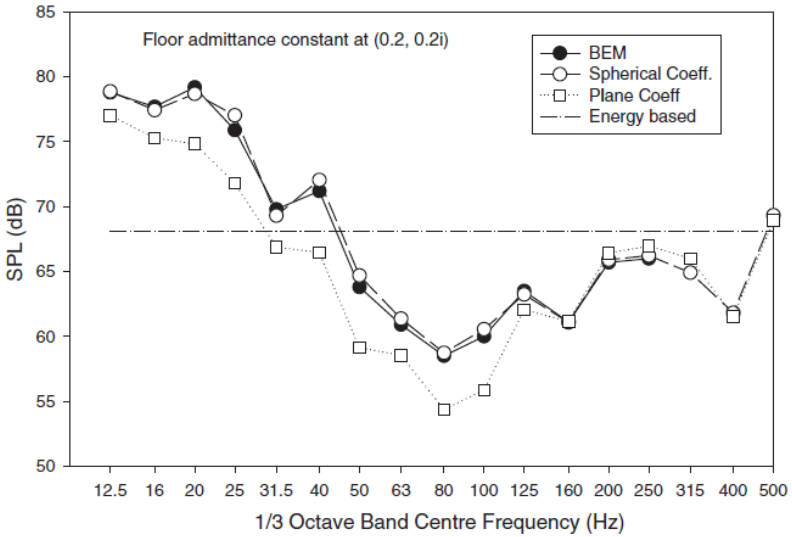
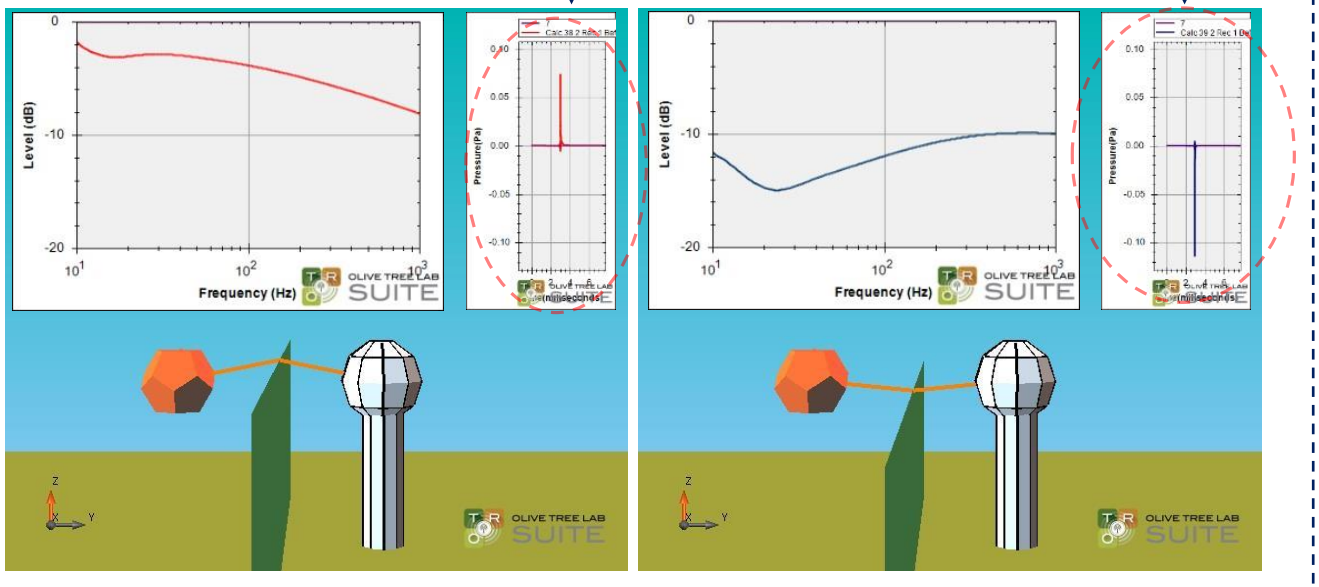


Fig. 10 1/3 octave results of Fig. 9.

PART 3 – SOUND DIFFRACTION
&
ITS SIGNATURE

PART 3 – SOUND DIFFRACTION & ITS SIGNATURE

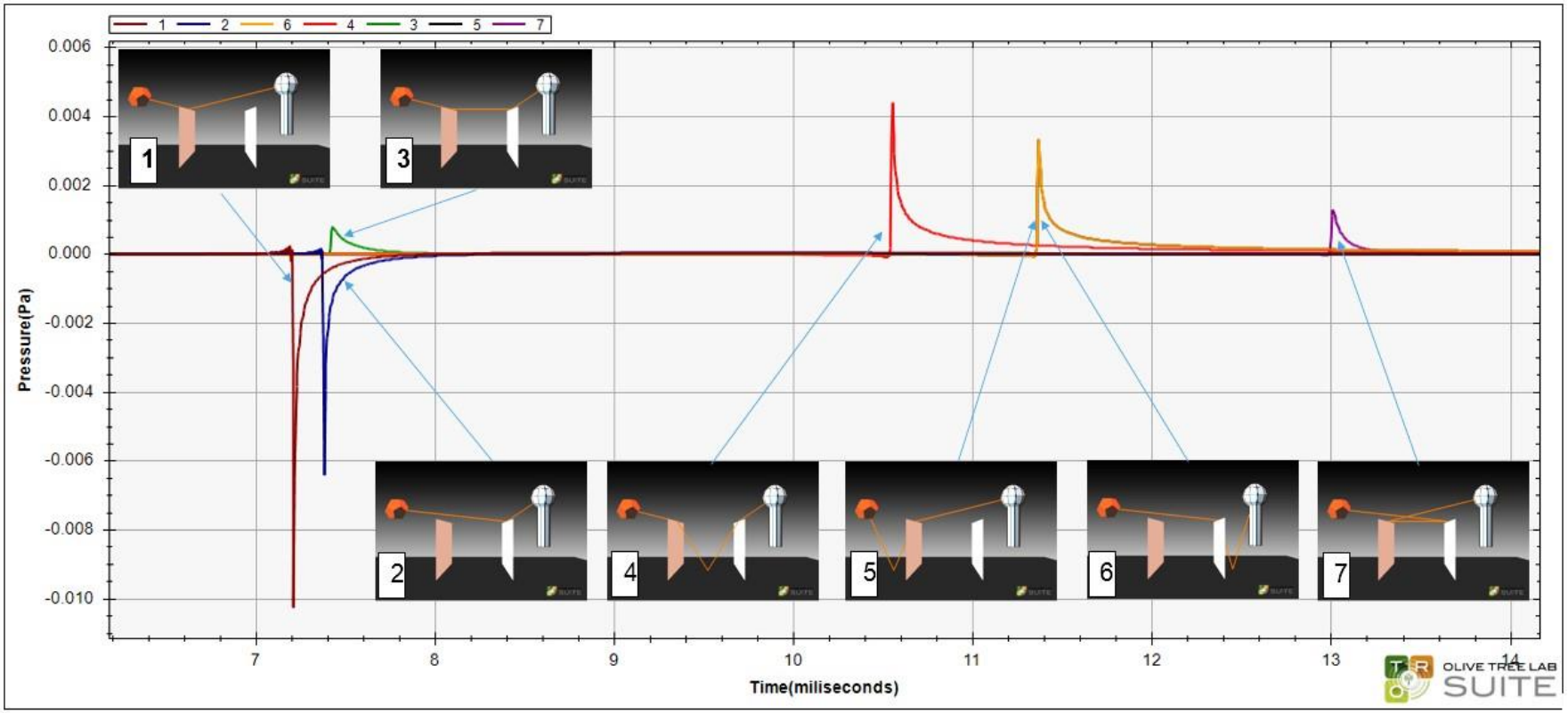
The inset graphs on the left of each picture show the frequency domain, while on the right time domain.



- When a barrier shields the sound path between source and receiver, the diffracted path has no phase change.
- When there is direct sound, the diffracted path has a phase reversal and becomes negative.

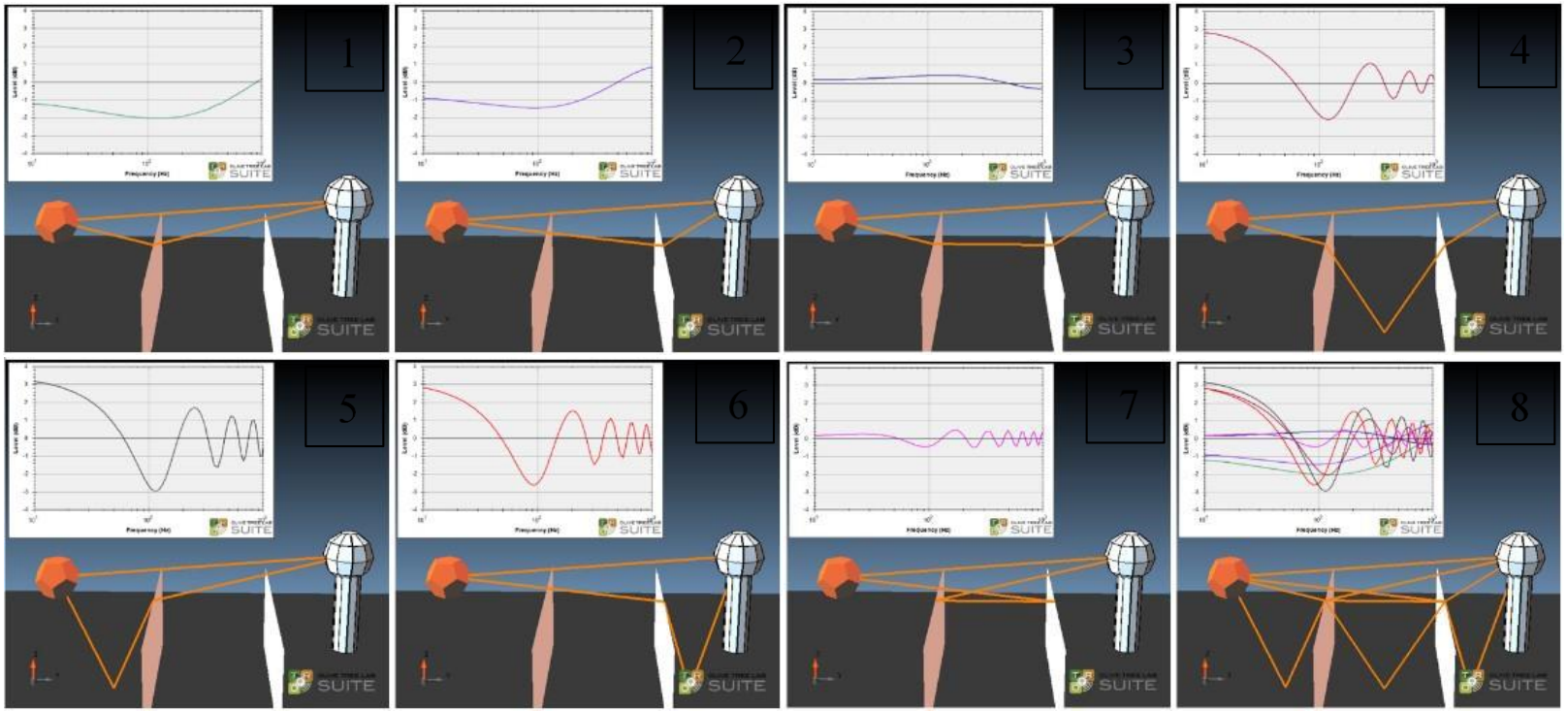
PART 3 – SOUND DIFFRACTION & ITS SIGNATURE

The first 7 sound paths including combinations of diffracted - reflected paths off the floor between 2 barriers. The direct sound path is not shown.



PART 3 – SOUND DIFFRACTION & ITS SIGNATURE

The individual contribution of the first 7 sound paths combined with direct sound (as is the case of ancient theatres). The last picture shows all of the paths together for comparison purposes.



PART 4 – VALIDATION OF WBGA

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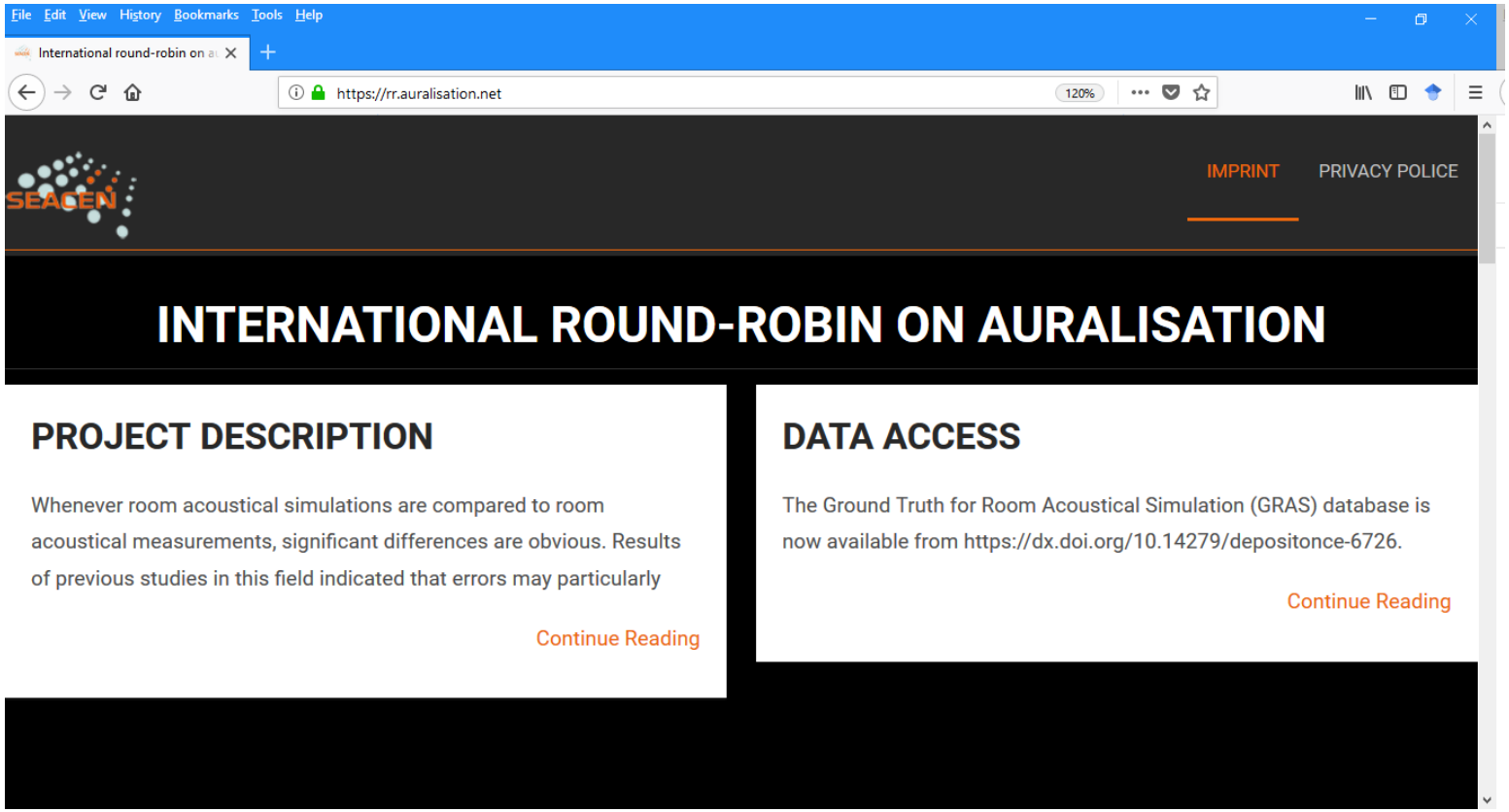
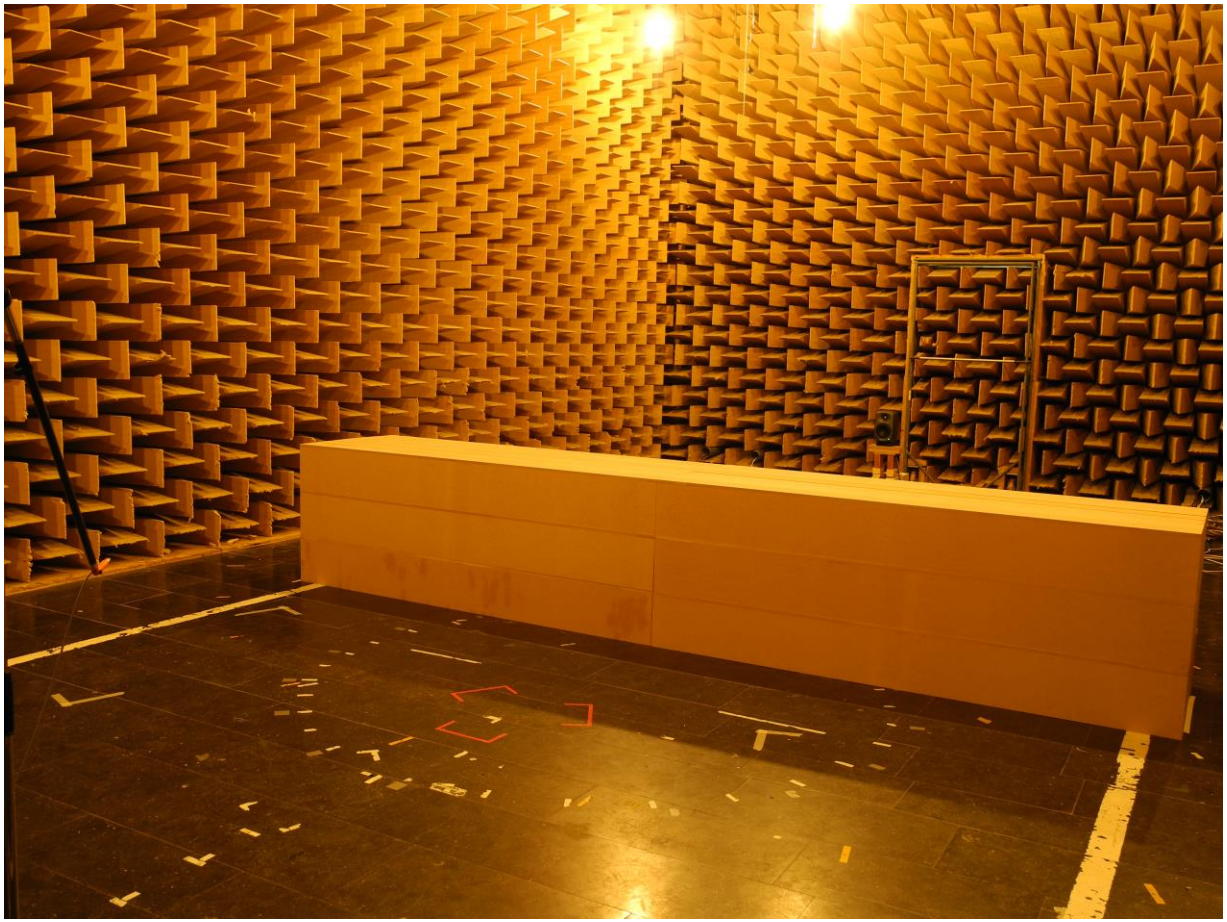
In order to validate our calculations we have used measured data provided by the **International round-robin on auralisation** https://rr.auralisation.net/



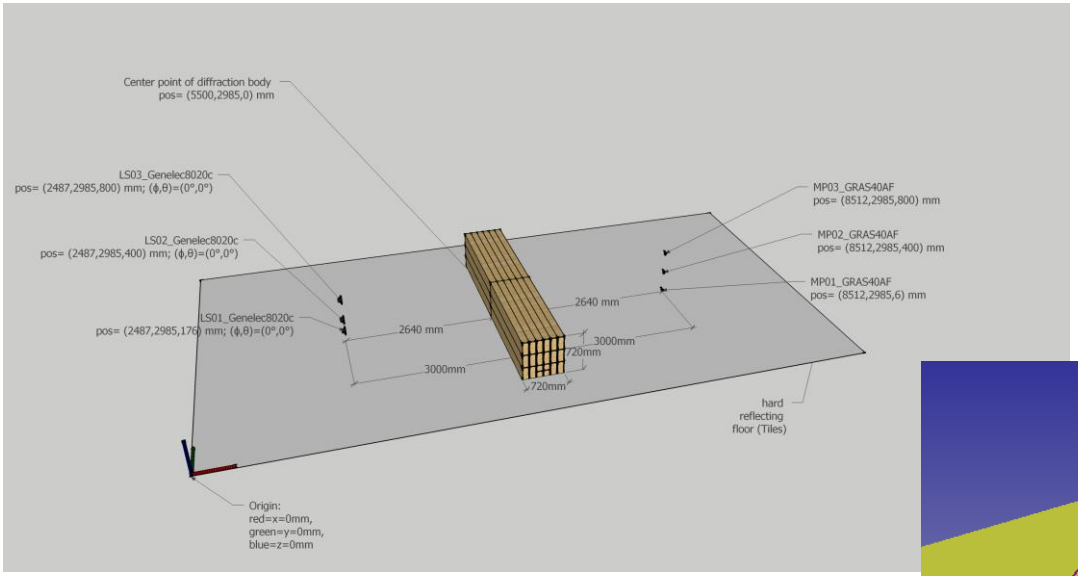
PART 4 – VALIDATION OF WBGA

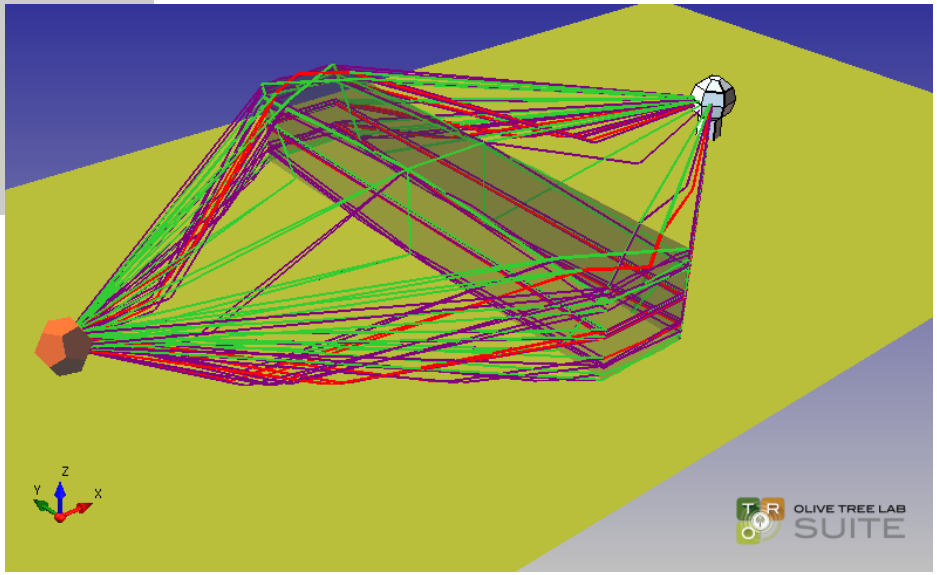
This is the set up used to calculate **Finite Body Diffraction**. Measurements and geometry are provided by the project



PART 4 – VALIDATION OF WBGA

The geometry used to calculate Finite Body Diffraction, given by the project in SketchUp. Also, the same setup in “OTL – Suite”, a WBGA software by PEMARD.





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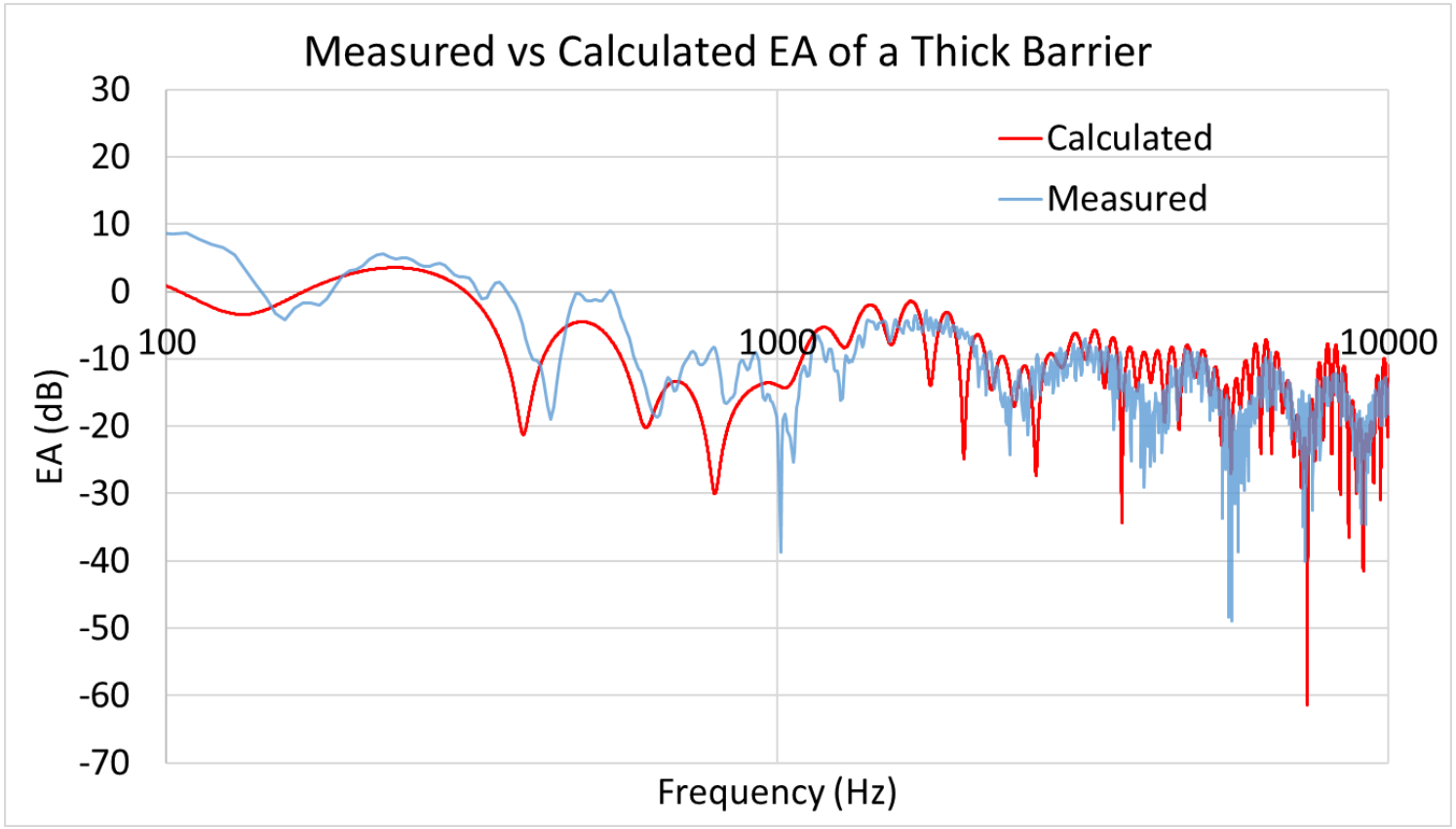

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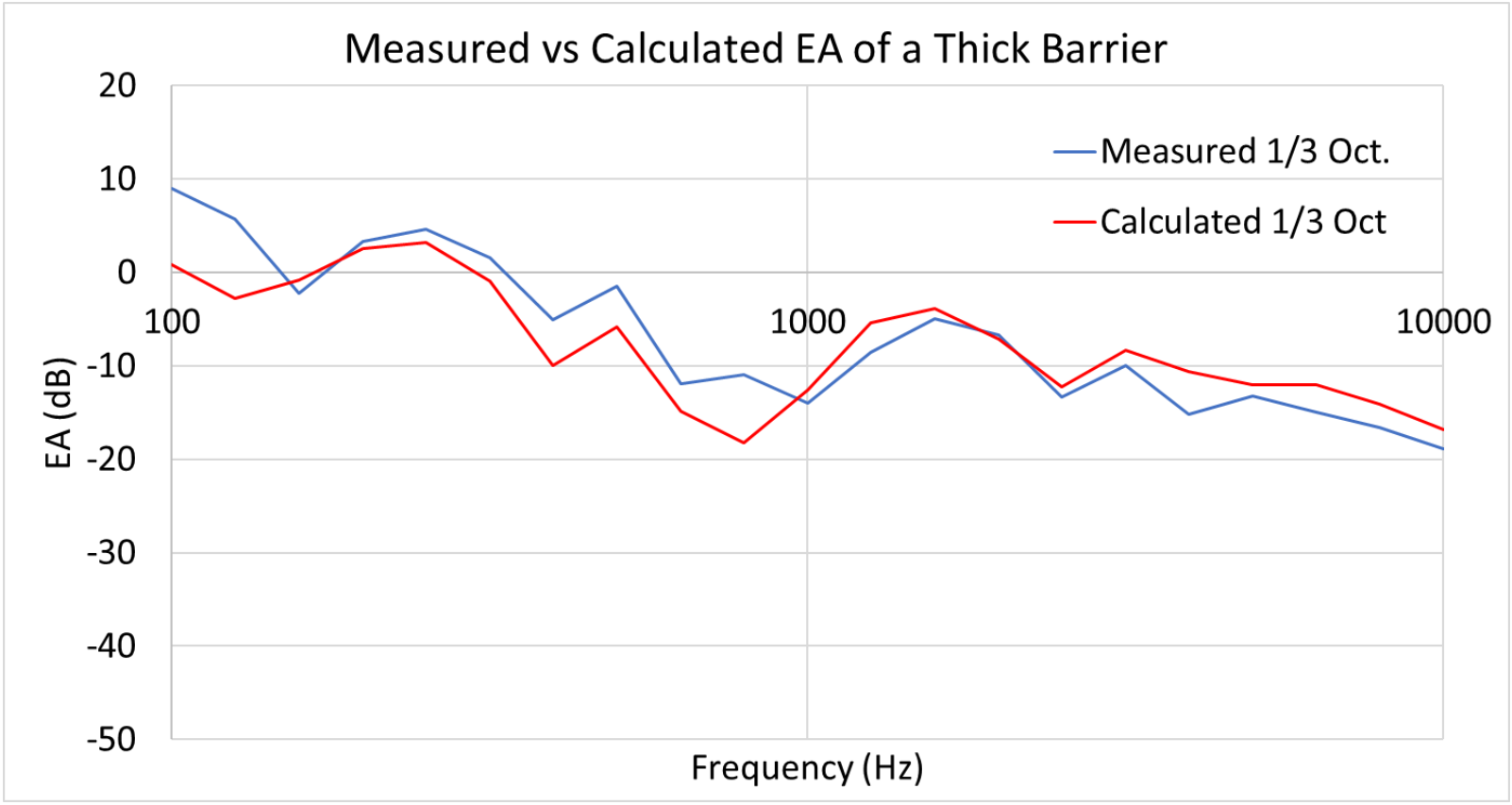

PART 5 – MEASUREMENTS & ACOUSTICAL MODELLING

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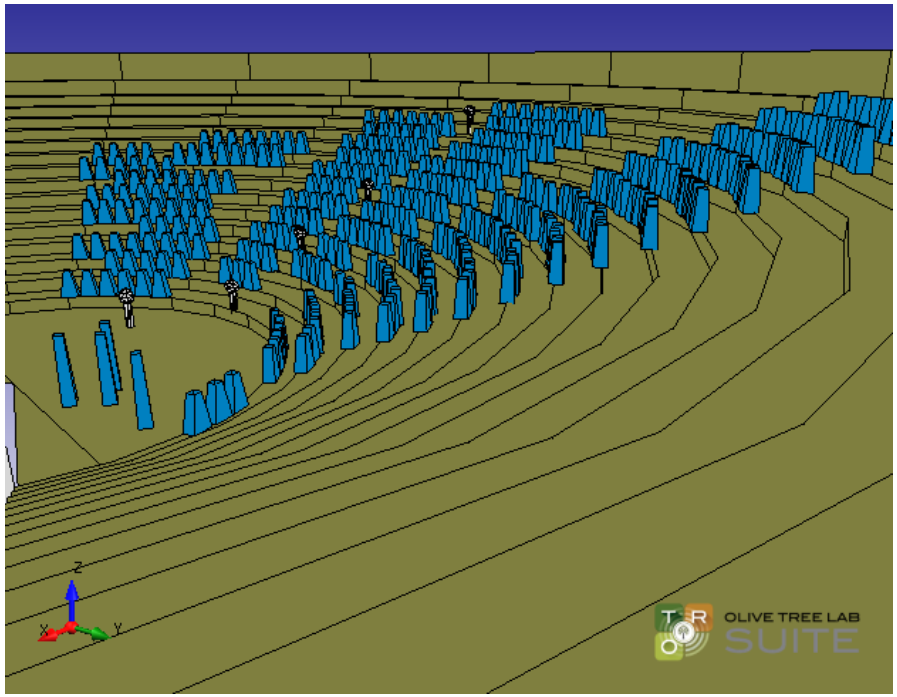
The Heritage Private School Theatre has the following characteristics:

- 15 rows of seats, each on average 0.37 m high and 0.91 m deep.
- The radius of the Orchestra is approximately 6.18 m while the entire radius of the theatre is approximately 19.85 m, with an arc spanning 220 degrees. The opening of the cavea is 140 degrees.
- The theatre capacity is of the order of 1500 people.
- 4 microphones were placed in the Cavea and 1 in the Orchestra.

PART 5 – MEASUREMENTS & ACOUSTICAL MODELLING

WITH AUDIENCE: On the Left during measurements. Right modelling.

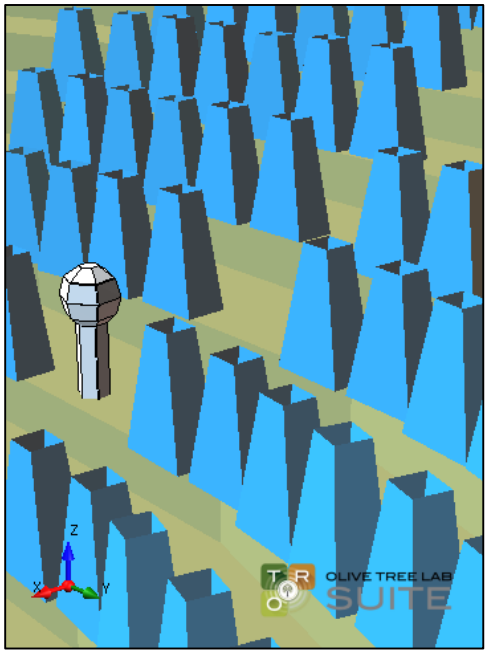
- The theatre capacity is of the order of 1500 people.
- During measurements 432 students acted as spectators.

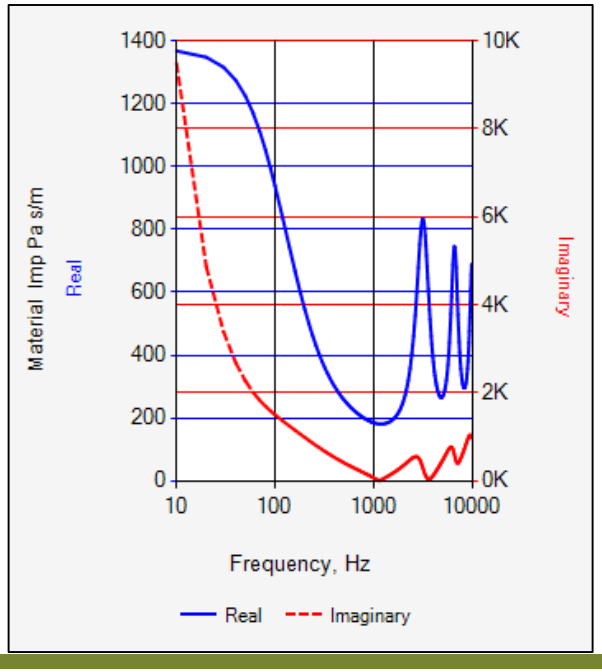


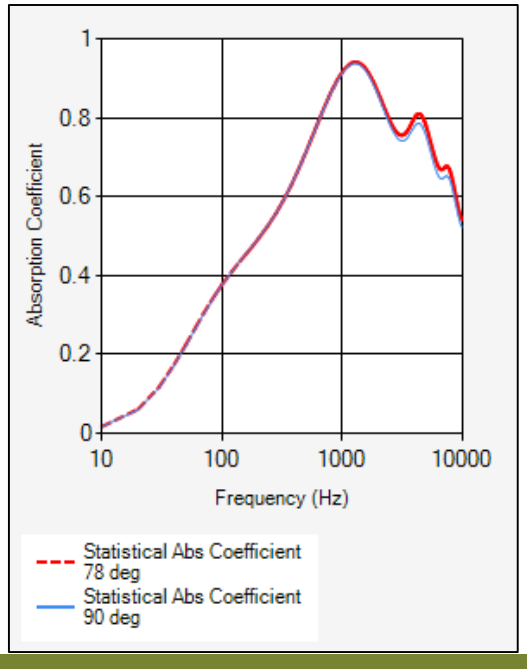
PART 5 – MEASUREMENTS & ACOUSTICAL MODELLING

ASSIGNED SHAPE & IMPEDANCE TO AUDIENCE AND THEATRE STRUCTURE

- Each audience member was modeled as a trapezoidal shape with base dimensions of $0.5x0.3m^2$ & top dimensions of $0.2x\ 0.2m^2$ & a height of 0.8 m.
- Theatre structure impedance was according to the Delany-Bazley model (flow resistivity of 20MkPas/m2) while the audience impedance was modeled according to the Allard and Johnson methodology. ***For easier interpretation***, the equivalent statistical sound absorption coefficients are also shown, ***NOT used in any of the calculations***.







PART 6 – RESULTS: MEASUREMENTS VS SIMULATIONS

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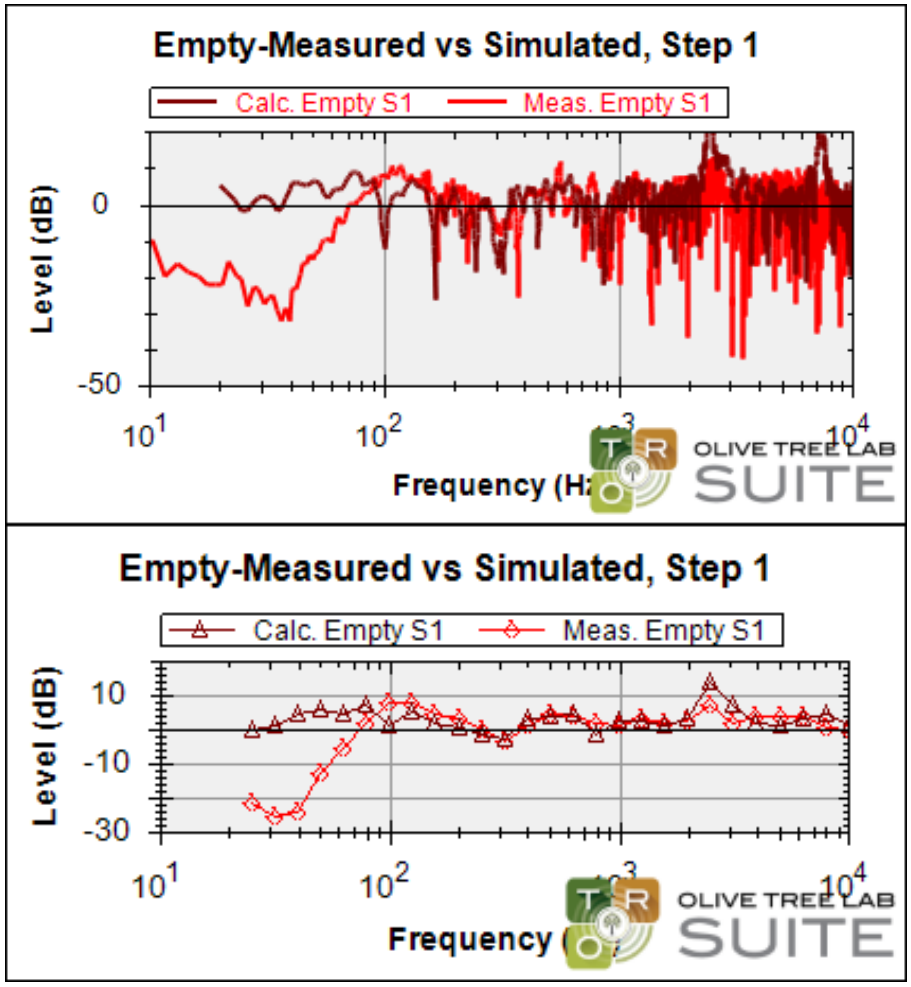
EMPTY THEATRE: Relative Levels at **Step1** out of 15, Closest to source

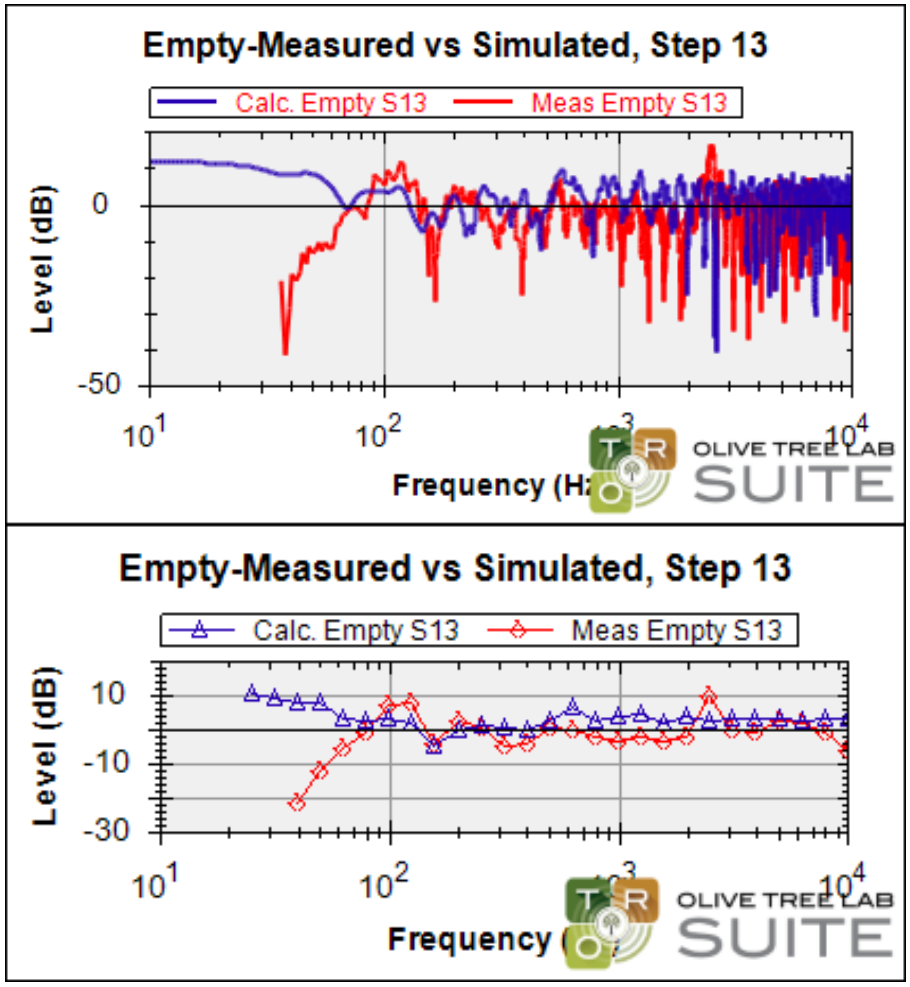


High Resolution Frequency Analysis

1/3rd Octave Analysis

PART 6 – RESULTS: MEASUREMENTS VS SIMULATIONS

EMPTY THEATRE: Relative Levels at **Step13** out of 15, Furthest from source

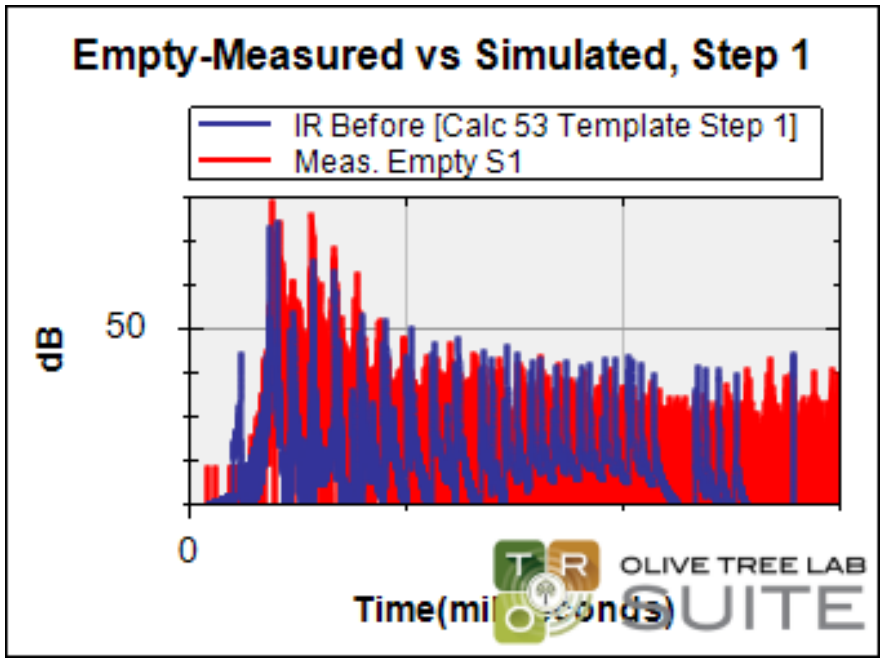


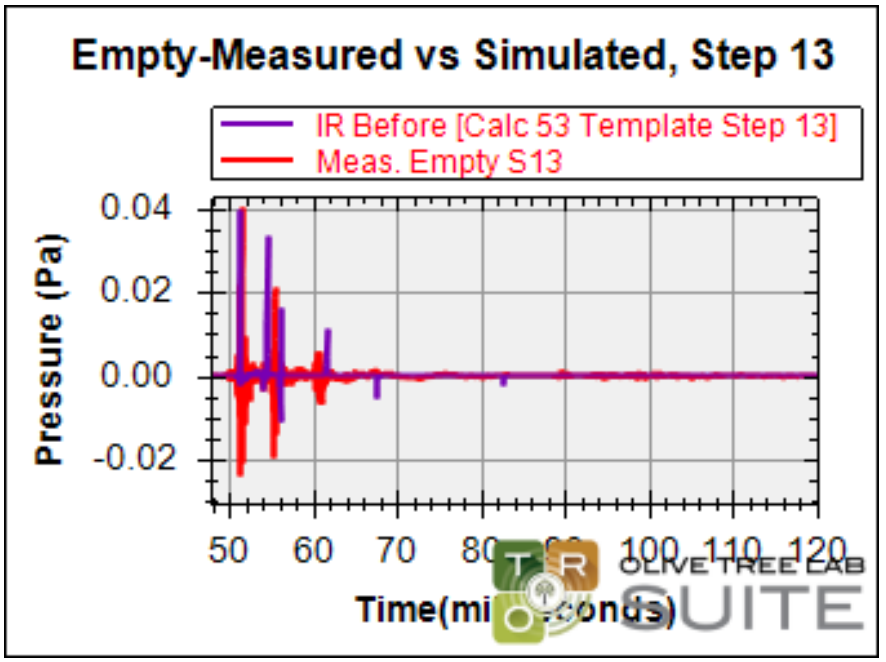
High Resolution Frequency Analysis

1/3rd Octave Analysis

PART 6 – RESULTS: MEASUREMENTS VS SIMULATIONS

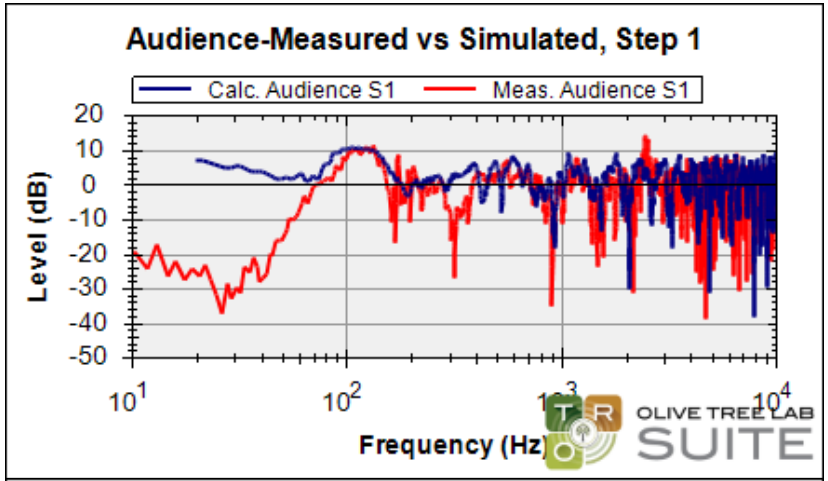
EMPTY THEATRE : Impulse Response Steps 1 & 13



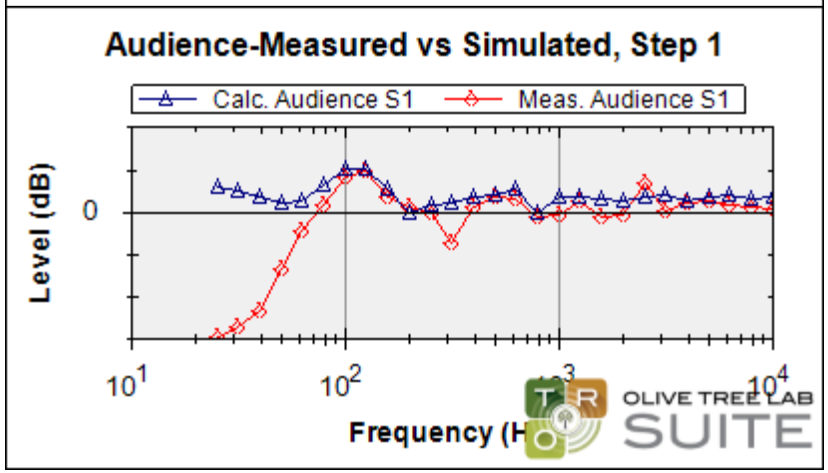


PART 6 – RESULTS: MEASUREMENTS VS SIMULATIONS

THEATRE WITH AUDIENCE : Relative Levels at Step1



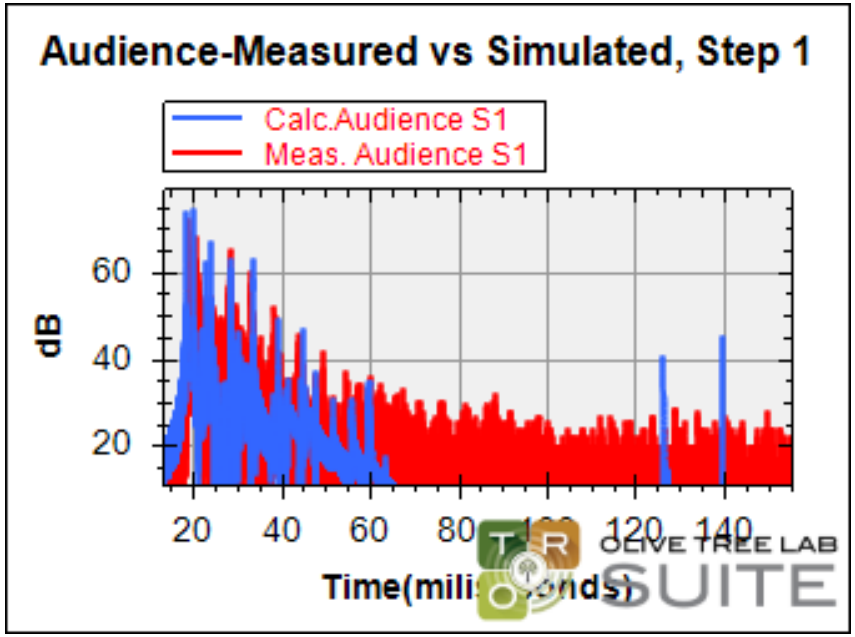
High Resolution
Frequency Analysis

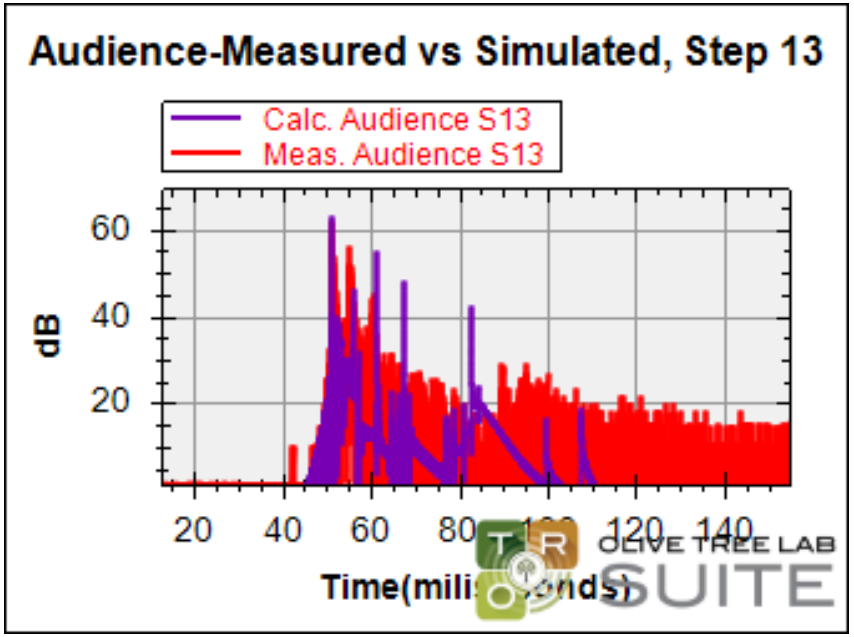


1/3rd Octave Analysis

PART 6 – RESULTS: MEASUREMENTS VS SIMULATIONS

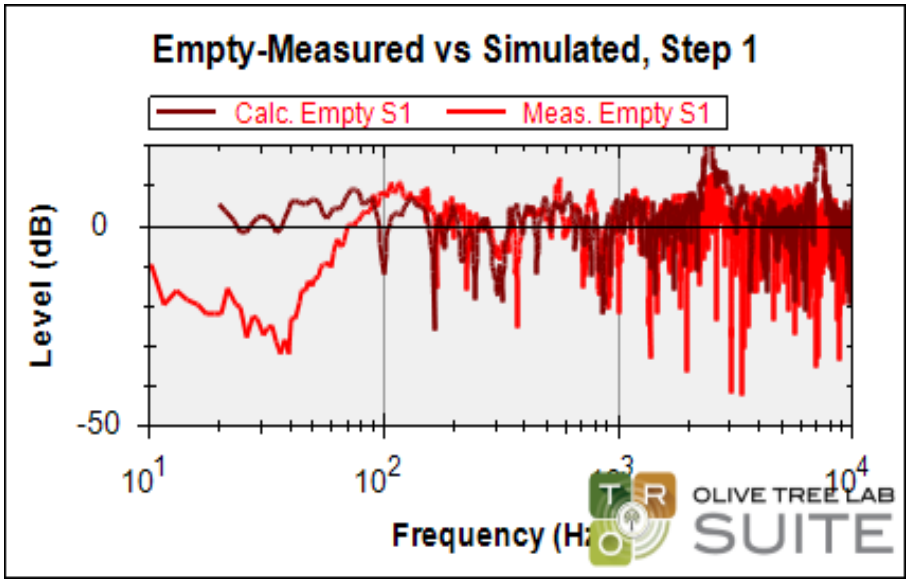
THEATRE WITH AUDIENCE: Impulse Response Steps 1 and 13

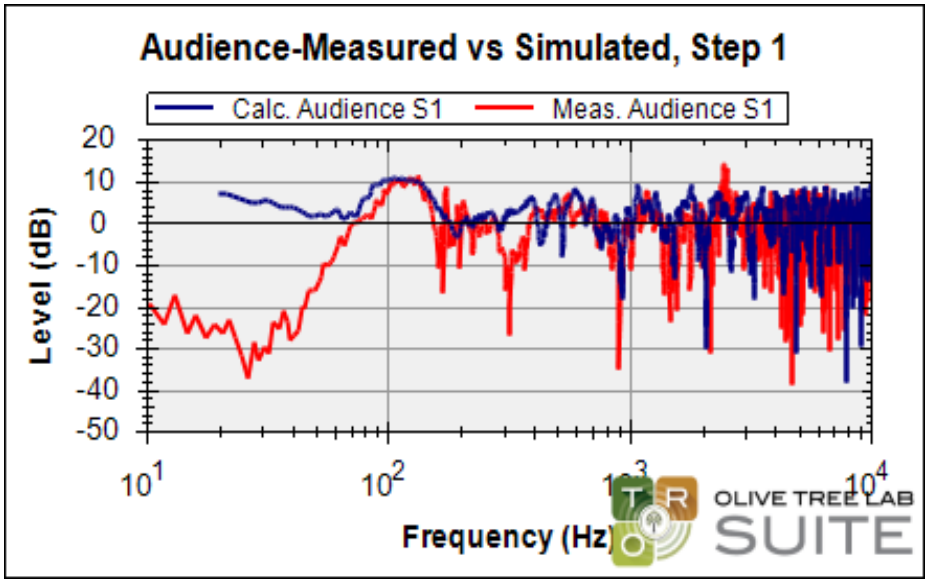




PART 6 – RESULTS: MEASUREMENTS VS SIMULATIONS

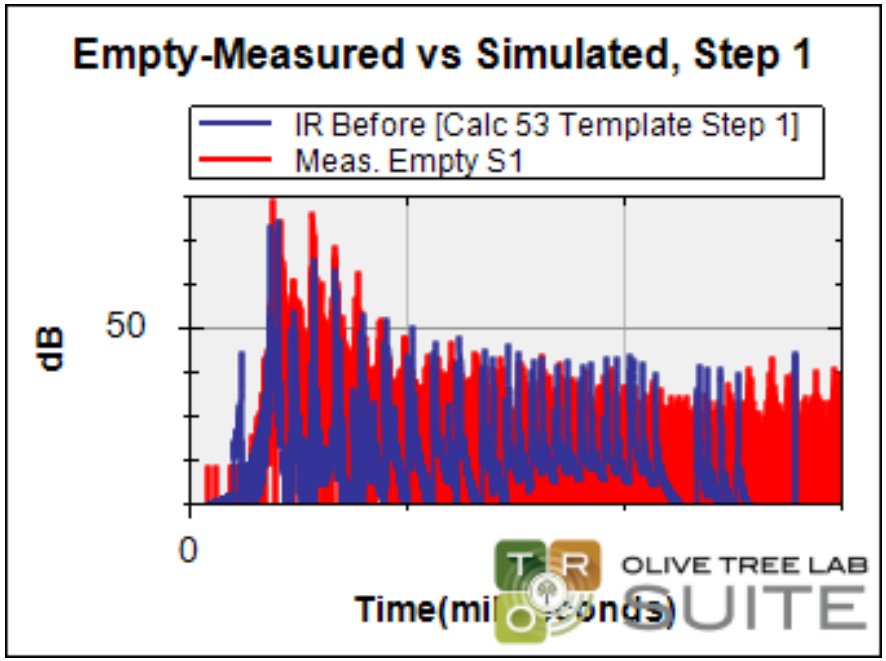
THEATRE WITH & WITHOUT AUDIENCE: Relative Level Step 1

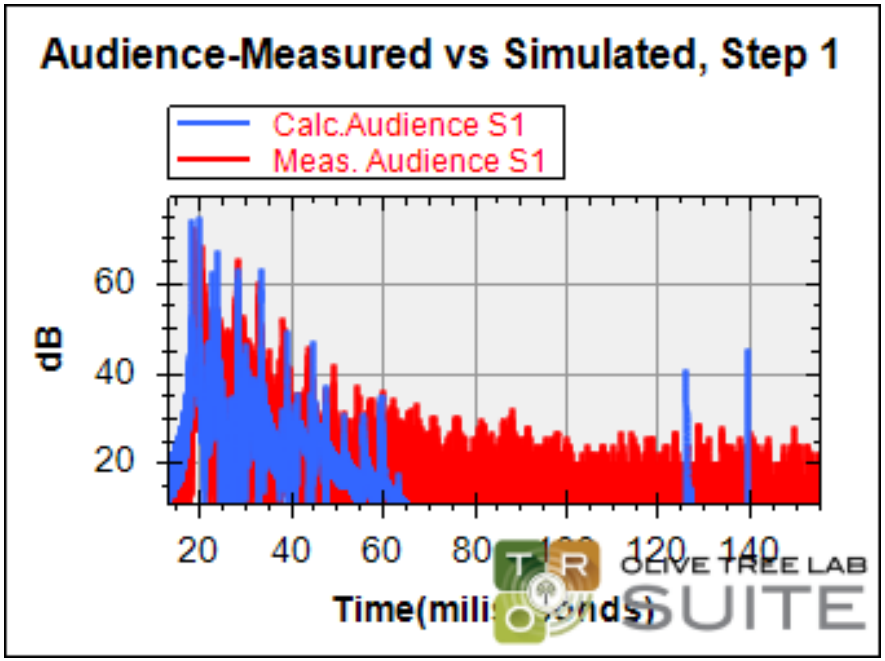




PART 6 – RESULTS: MEASUREMENTS VS SIMULATIONS

THEATRE WITH & WITHOUT AUDIENCE: Impulse Response Step 1





PART 6 – RESULTS: MEASUREMENTS VS SIMULATIONS

Measured Speech Parameters

Broadband	C50 (dB)		D50 (%)	
	EMPTY	AUDIENCE	EMPTY	AUDIENCE
Orchestra	18.4	24.0	98.58	99.6
S1	21.0	25.3	99.2	99.7
S4	21.1	25.4	99.2	99.7
S7	20.5	25.2	99.1	99.7
S13	19.0	20.5	98.8	99.1

PART 7 – POLAR PLOTS

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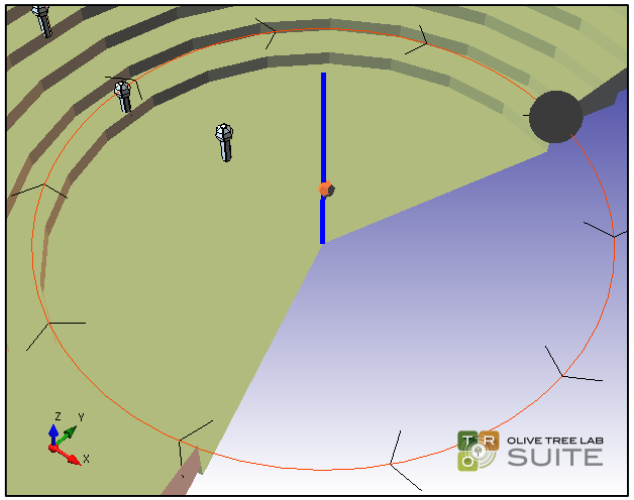
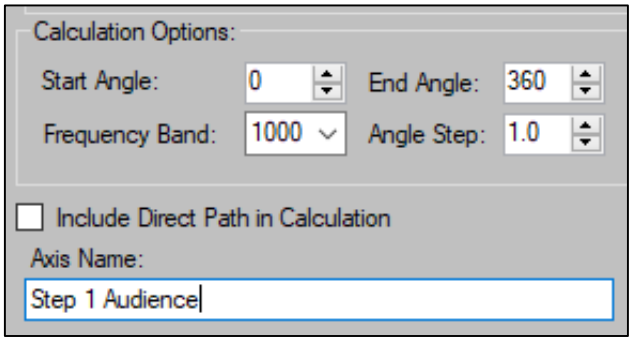
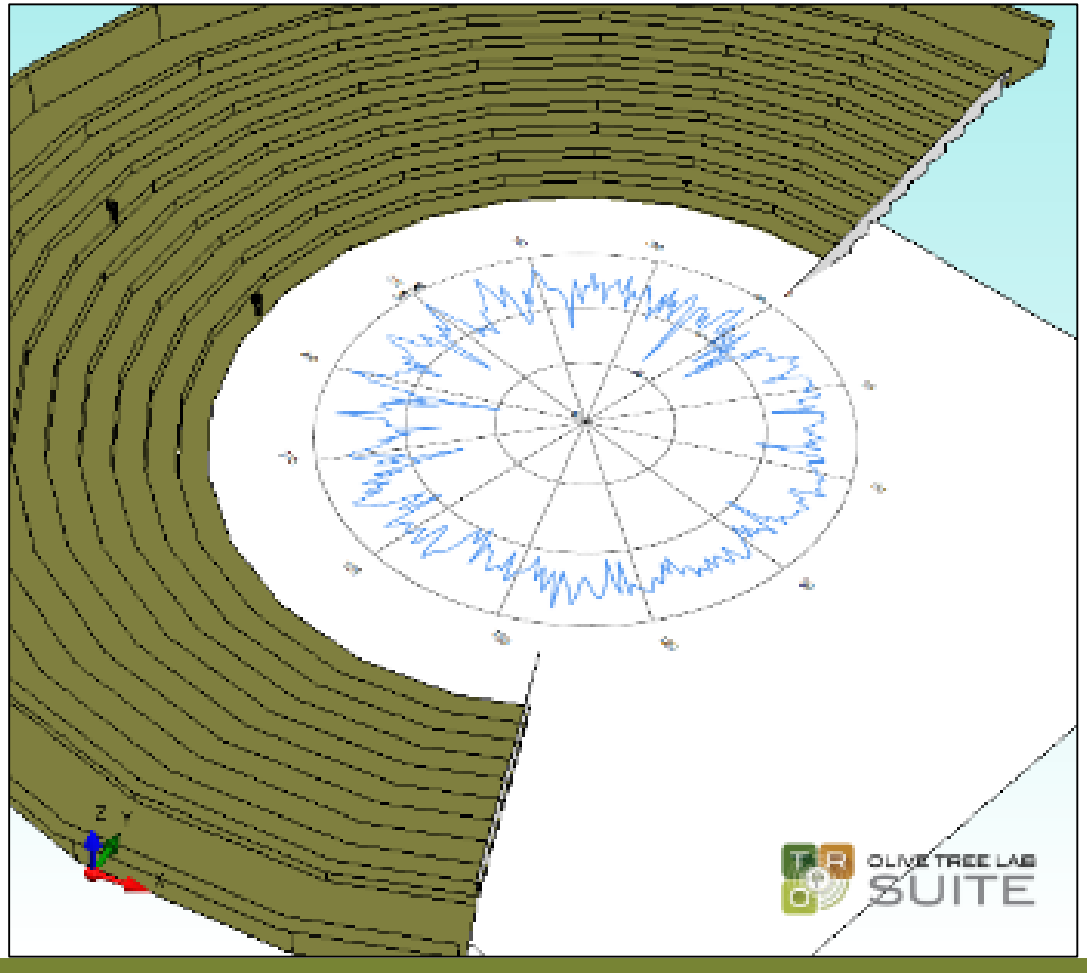
How Polar Plots are calculated

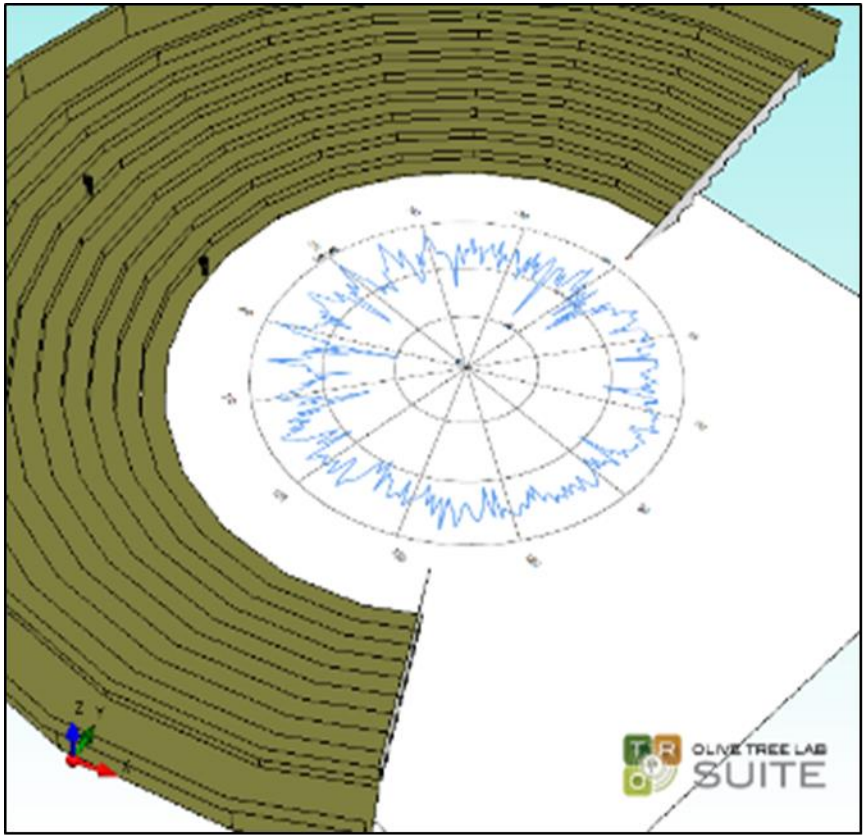


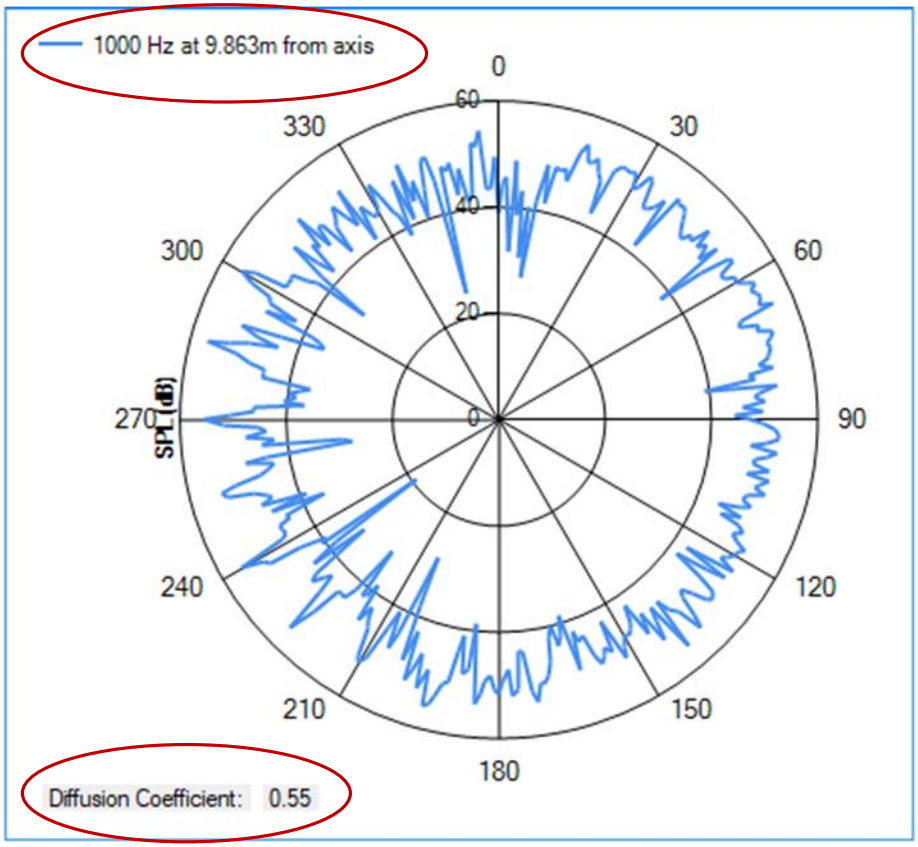




PART 7 – POLAR PLOTS

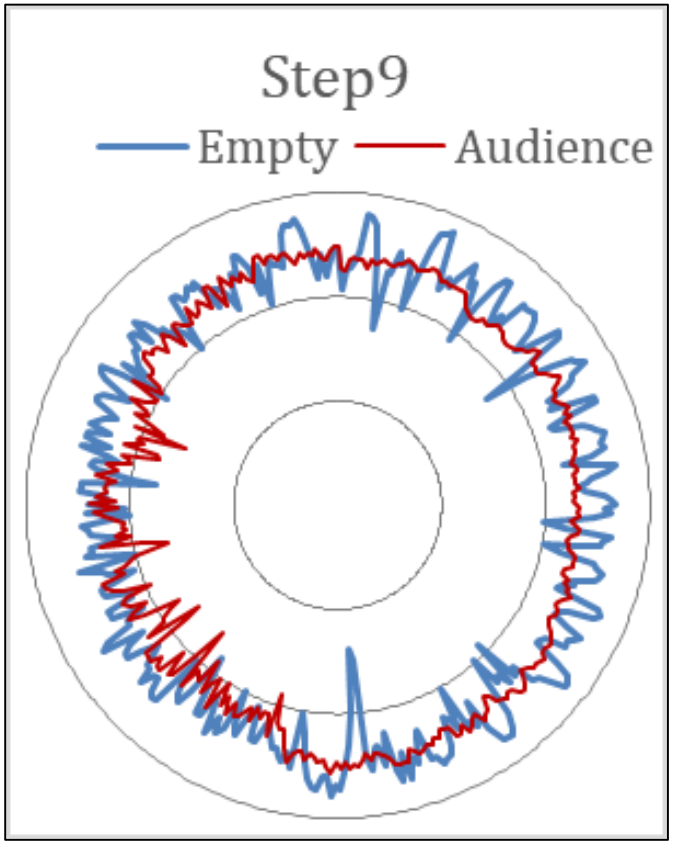
How Polar Plots are calculated. Diffusion Coefficient according to ISO 17497-2





PART 7 – POLAR PLOTS

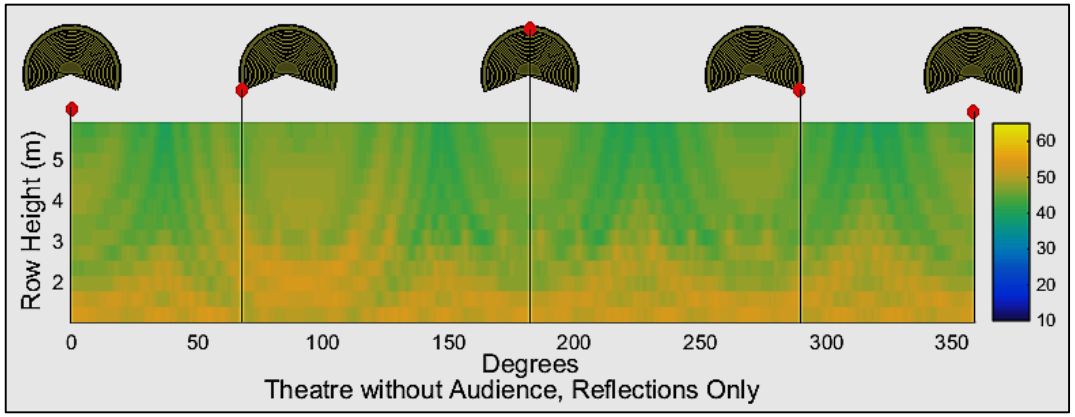
Example: Polar Plot at Step 9, with and without Audience



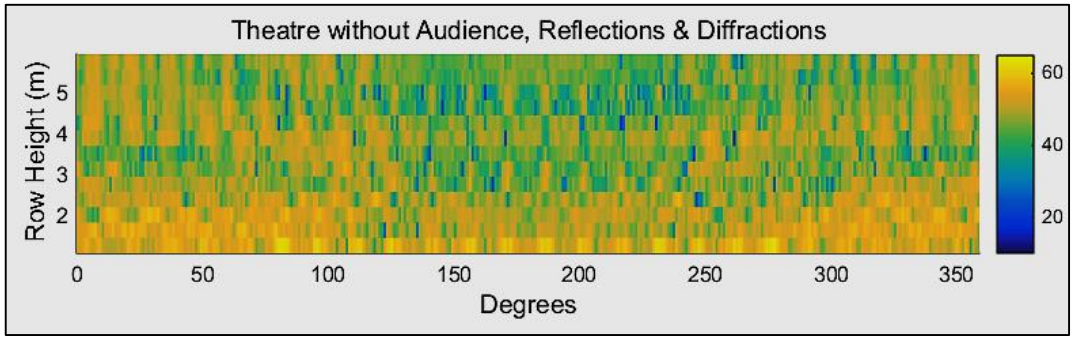
PART 7 – POLAR PLOTS

Mapping Using Polar Plots at 1kHz

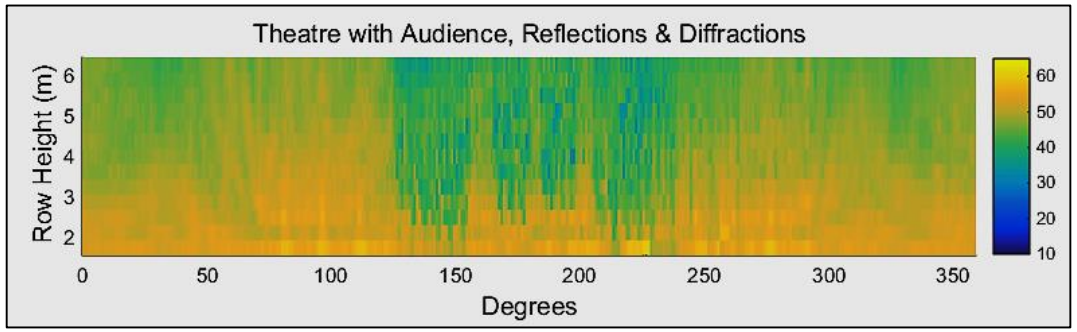
Without Audience
Reflections Only



Without Audience
Reflections & Diffractions

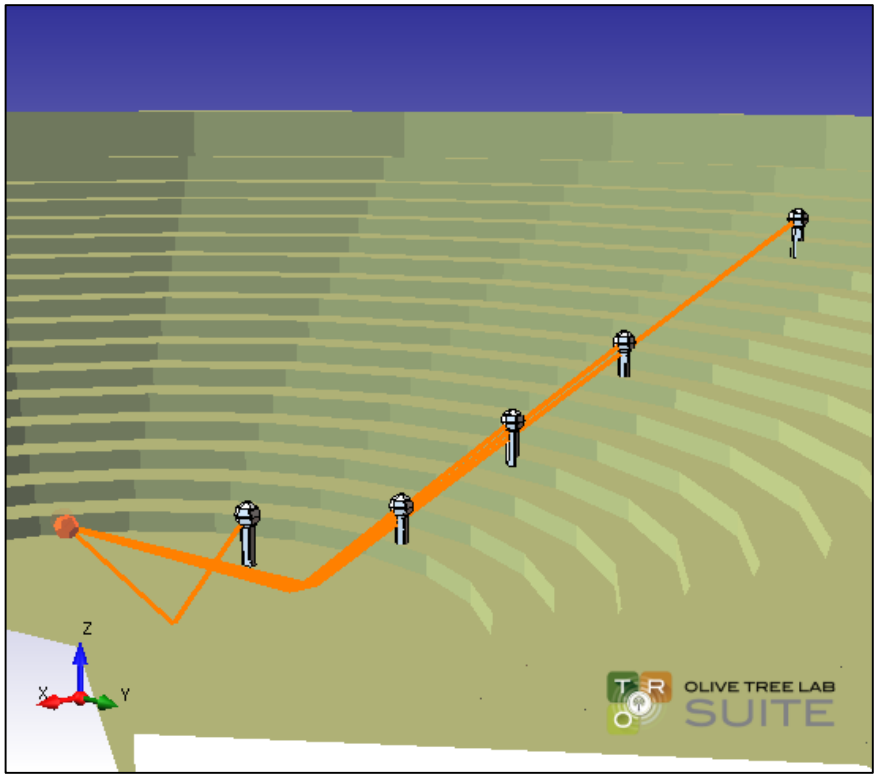


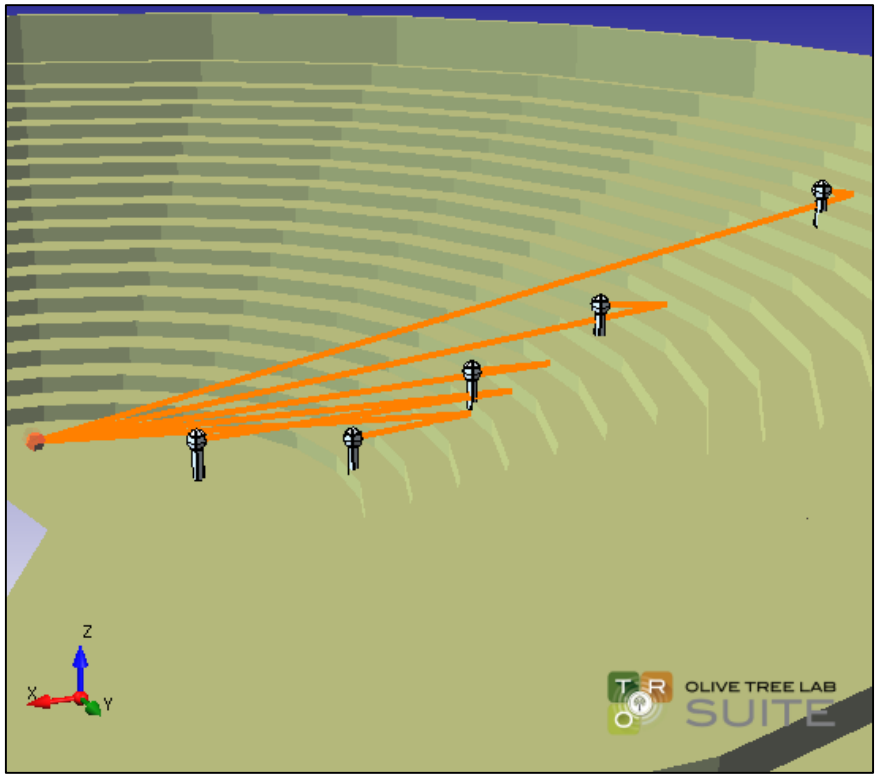
With Audience
Reflections & Diffractions



PART 7 – POLAR PLOTS

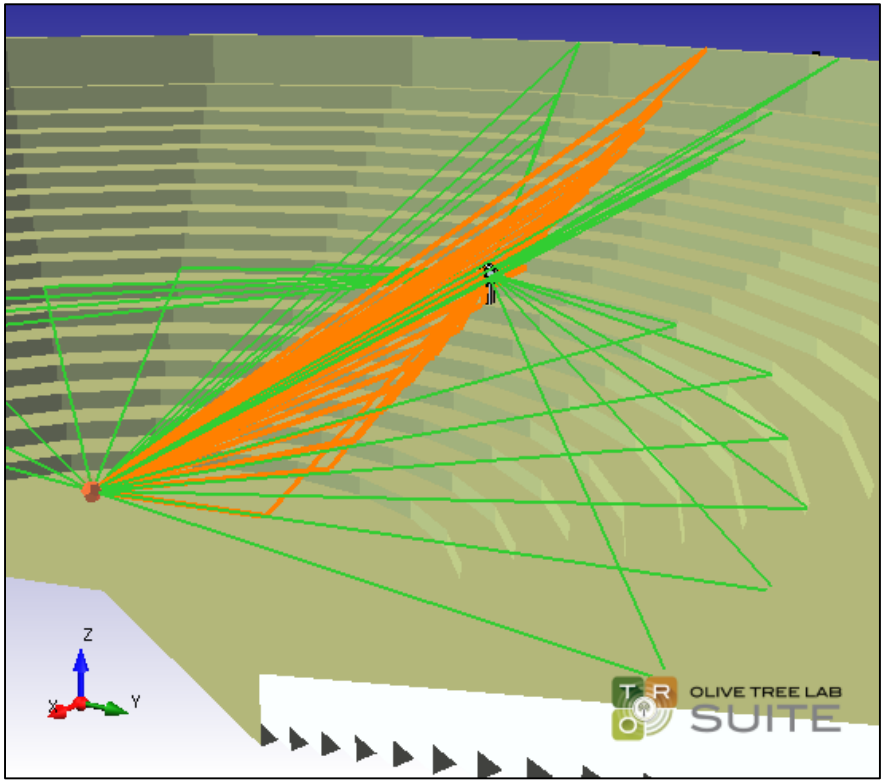
Reflections from the orchestra and the back rows, depending on seating arrangement, are eliminated by Audience.



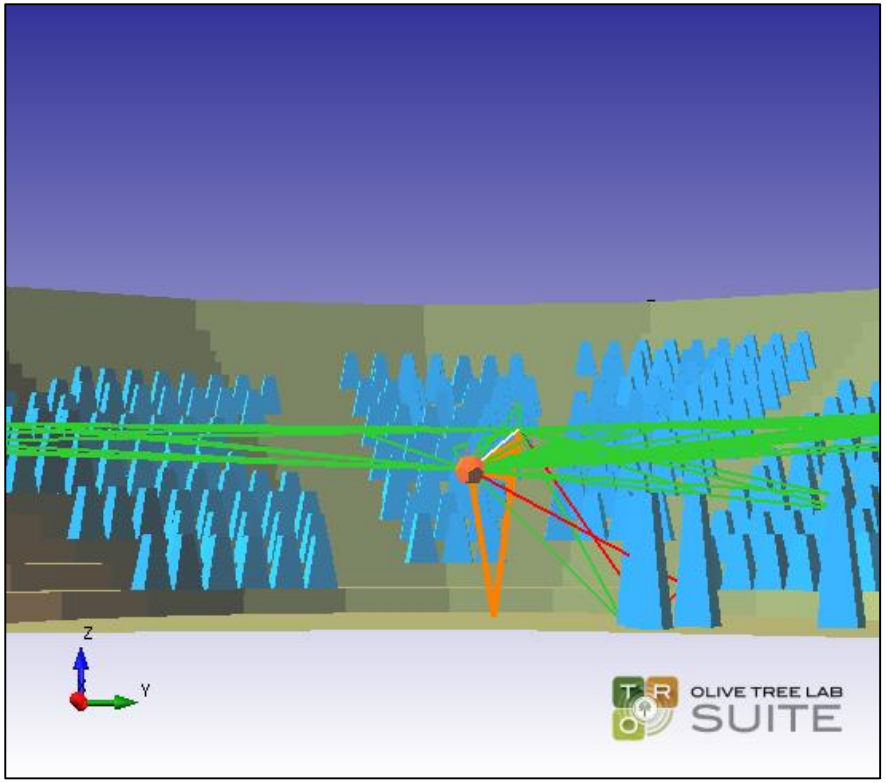


PART 7 – POLAR PLOTS

Diffractions from an Empty Theatre



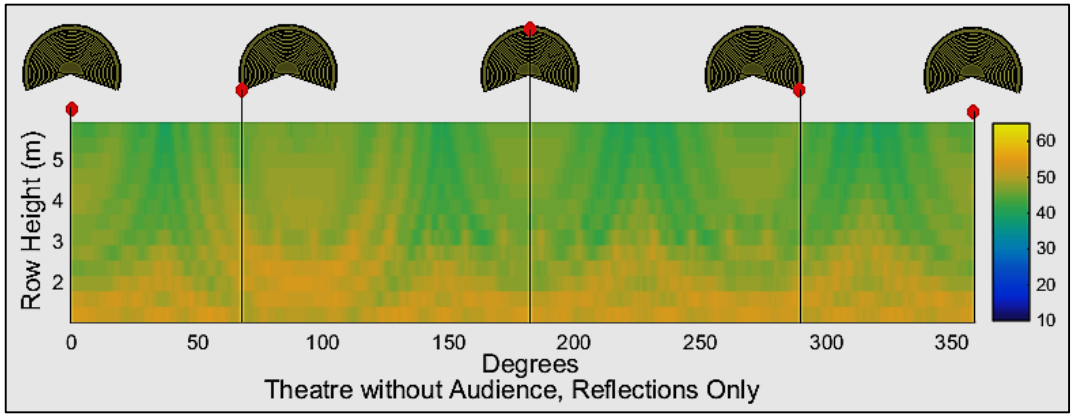
Diffractions, which depending on seating arrangement, are either **eliminated** (in orange) or **enriched** by Audience.



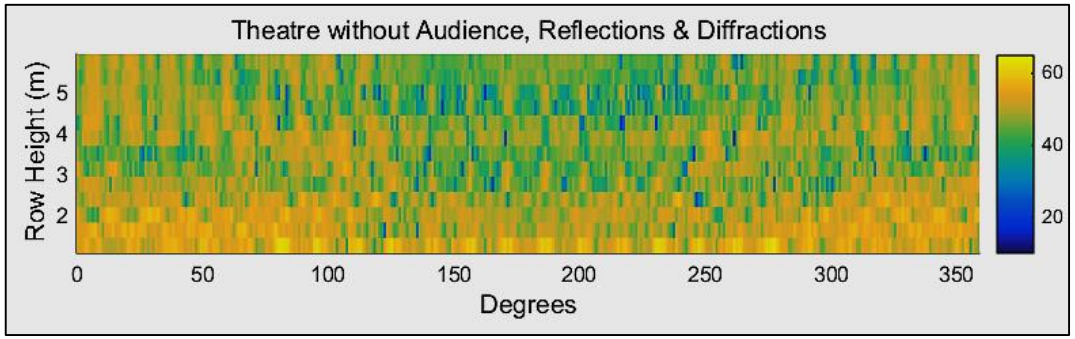
PART 7 – POLAR PLOTS

Mapping Using Polar Plots at 1kHz

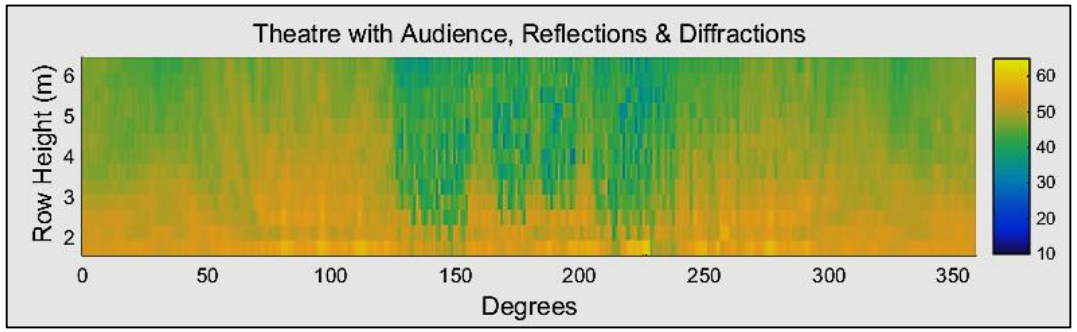
Without Audience
Reflections Only



Without Audience
Reflections & Diffractions



With Audience
Reflections & Diffractions



PART 8 – CONCLUSIONS

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a. The work has shown that the presence of audience, indeed assists speech and theatrical performances.
b. The presence of audience decreases late sound energy thus increasing speech clarity.
c. Since an audience is sound absorptive, it scatters sound less pronounced than Cavea steps.
d. Simulations show that sound diffraction or scattering from an audience, provide a more even sound distribution within the cavea.
e. Furthermore, all calculations show that useful sound energy escapes to the surroundings especially in the direction of the orchestra.
f. This suggests that ancient theatres utilized the proscenium not only for staging effects but also for preserving useful sound energy.

PART 8 – ACKNOWLEDGEMENTS

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