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THE ACOUSTIC DESIGN OF THE OLIVIER HALL IN OXFORD, UK

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ABSTRACT

The design of rooms for unamplified music requires careful consideration of volume, shapes and materials to obtain the best acoustic conditions and sound coverage. The use of concave architectural elements is generally avoided in auditorium because it can produce acoustic defects such as sound focusing, uneven sound distribution, image shift and echo.
This paper presents the acoustic design, the simulated and measured acoustic parameters, of the 1000-seat oval shaped Olivier Hall, a state-of-the-art performance venue, situated within the prestigious St. Edward's School in Oxford. This award-winning Hall is part of a modern academic centre located on the School's historic Quad. The Hall brings the School and the surrounding community together by serving as a hub for various events and performances. Its oval design, reminiscent of Oxford's Sheldonian Theatre, contributes to its notable acoustics.

Keywords: *Concert Hall Sound, Room Acoustics, Concave Surfaces, Oval*

1. INTRODUCTION

The Olivier Hall, together with the Christie Centre is part of a major expansion of the St Edward's School campus in Oxford. The development, designed by TSH architects, includes the concert hall, a library, a reading room, offices, teaching, collaboration and study spaces.
The project was completed in 2020 and won the RIBA South Award in 2022.

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2. OLIVIER HALL

2.1 Usage

The centrepiece of the new development is the Olivier Hall, a new ~1000 seats hall that has been designed to accommodate different usages including:

- School assembly, lectures
- Chamber music concerts and rehearsals
- Dance performances and rehearsal
- Amplified concerts
- Theatrical performances
- Organ recitals

2.2 Location

The building is located within the existing campus in a relatively quiet environment at a distance of ~120m from the closest busy road. Average daytime environmental noise levels have been measured to be 52dB $L_{AEq,30min}$.

2.3 Layout

The hall is an independent building, served by three access stairs and a lift, developed over five levels (Fig.1):

- The basement is occupied by plant, changing rooms and storage.
- At ground floor is located the foyer and café that are connected via accessible sound and light lobbies to the hall at stalls and stage level. The stalls consist of a flat area with loose seats and a raked slope with fixed seats.
- Two balcony levels are arranged with seating located in the round. The seats at the rear of the stage are used by the choir.
- At the top of the room there is a technical level over a tension wire grid floor to provide flexibility in terms of stage lighting and rigging required for different usages.

2.4 Seating Capacity

The maximum number of people that the room can accommodate is ~1000, distributed in fixed seats (~600), loose seats (~300) and with standing positions at balcony levels.
Events such as assembly, lectures etc. can host up to a 1000 people audience. Other uses, such as orchestra and chamber music concerts, dance shows require a much bigger stage that is achieved by removing the loose seats and possibly the raised demountable stage. For these events the capacity of the hall usually does not exceed the number of fixed seats (600).

2.5 Room Acoustics

The room acoustic design has been developed to satisfy the needs of all the different usages with good clarity of speech and music.

3. CONCAVE SURFACES

3.1 Why concave geometry could be detrimental?

The behaviour of concave surfaces has been studied by different authors [1],[2],[3],[4]. These surfaces can produce acoustic defects such as sound focusing, uneven sound distribution, image shift and echo.
The geometrical relationship between sound source, receivers, surface location, surface size and radius of curvature are key variables to take into account to determine if concave surfaces could create unwanted effects.

4. ROOM DESIGN

4.1 Finishes

The room finishes consist of timber floor at stalls level while carpet has been used for the audience at first and second balcony level to control footfall noise and reduce the change in reverberation time between the occupied and unoccupied room in the absence of a variable acoustic system.
Walls are covered with timber finish that provide a mass of at least 25kg/m2.
At first and second balcony levels, windows are located across the entire perimeter of the room. The availability of natural light is important during daytime use for assemblies and rehearsals.
Blackout is achieved during the day with timber panels that are located in front of the windows. Curtains have been deemed not suitable for this purpose to avoid adding additional absorption.
At technical level are located services (e.g. ducts) and infrastructure to support stage lighting, audio visual systems and rigging used for certain events. No fixed absorption is located within the technical level.

4.1.1 Seats

The fixed seats are upholseterd with an imperforate back and pan underside. (Fig.2)
The loose seats are stackable chair with minimum upholstery.

4.2 Acoustic volume

The overall acoustic volume of an auditorium influences both loudness and reverberation, key aspects of musical acoustics [6]. The ideal volume of a room should not only take into account the achievement of the target reverberation time but also chosen considering the music ensemble size and loudness control.
The volume (measured in cubic meters) is important and there are minimum values below which we would not advise due to potential loudness issues.
In a hall for music the only sound absorbing element usually tends to be the audience. For this reason, at least in the initial stages of a project, we tend to benchmark rooms on volume weighted by the number of seated occupants (cubic meters per person).

The volume of the Olivier Hall, including the technical level, is ~4500m^3. This guarantees to achieve ~5m^3/person during-high-capacity events and ~7-8m^3/person for chamber music and dance when loose seats are removed.

4.3 Hall Shape

The oval shape of the hall, in plan, (Fig.3) has concave surfaces that could create uneven sound distribution and focusing effects.

5. ANALYSIS

Parametric geometric analysis [7], developed with Grasshopper and Rhinoceros [8], have been used together with Catt Acoustic simulations [10] to evaluate sound reflections patterns within the room and evaluate the possible location of sound focusing.
The raytracing approach can provide insight of the problem at mid and high frequencies, low frequencies analysis would require a wave-based approach that was not undertaken for this project.

Raytracing diagrams, in the Figure section, show in red (absorbent) the audience and the sound source is indicated in pink.

5.1 Stalls

In the central part of the stalls the concave profile of the side walls is shallow. The wall is not continuous since wall diffusers are installed to provide fresh area. These elements provide a certain degree of absorption and help reducing the sound energy that is specularly reflected. (Fig 4)
The rear side walls have the potential to cause focusing due to their progressively smaller radius of curvature.
The raytracing diagram (Fig 5) shows that the focusing happens at first balcony level.
The case presented is an example and the location of the focus varies slightly changing the source location.

The analysis from Catt shows an increase in early Strength (G80) (Fig.6) and understandably also in Clarity (C80) (Fig.7) in the same locations where the focussing is indicated by the raytracing diagram (Fig 5).

Surface modulation has been integrated to help reducing the effect of the surface curvature.
The scale and dimension of such modulation is small and probably only effective at mid and high frequencies. (Fig.8)

5.2 Balcony levels

The elliptical walls at balcony levels, due to its higher position compared to the stage do not produce first order reflections towards the audience but the interaction between the wall and the balcony ceiling could create a 2^{nd} order reflection.
The diagrams (Fig.9) show that in both cases the main focus caused by the combined effect of perimeter wall and balcony ceiling happen above the heads of the audience and by the time the sound hits the audience and stage the reflection has a diffusing effect.

It needs to be noted that:

- The perimeter walls at first and second balcony levels are not flat, but columns are protruding within the space providing sound diffraction. (Fig.10)
- The acoustic models consider an audience block ~600mm above the FFL leaving more free wall area than in reality when people will provide absorption and sound scattering up to 1.2-1.3 m above FFL.

In the occupied room the audience would help reduce the portion of the wall able to reflect sound and at the same time increase the cut-off frequency and reduce the intensity of the specular reflections [2].

5.3 Sound transparent ceiling

The oval architectural visual ceiling (Fig.11) is located below the technical level, and it has been designed to be as sound transparent as possible so that the acoustic volume of the technical level is part of the main acoustic volume.
The central oculus floor, made with a tension wire grid (Fig.12), consists of tensioned steel cables, at a distance of 10cm while the visual oval ring ceiling is obtained with open weave steel mesh (Fig.13).
Behind the open weave steel mesh are, in certain locations, acoustic reflectors, with a mass of ~ 20kg/m2, located to achieve early sound reflections for the benefit of the audience and the musicians on stage.

The reflections from the overhead reflectors are shown in diagram in Fig.14.
A focus happens in mid-air but does not affect negatively the audience. Reflections from these panels arrive in the 60-80 ms time window.

Reflections from the upper roof surfaces is affected by all the technical/ theatrical infrastructure, the steel structure of the roof and ductworks (Fig.15). These elements provide a considerate diffraction effect.

6. ACOUSTIC COMMISSIONING TESTS AND RESULTS

Acoustic commissioning tests have been undertaken, in the unoccupied room without loose seats, to evaluate various acoustic aspects of the building from sound insulation, background noise levels, and room acoustics [9].
An omnidirectional sound source, dodecahedron, was used to undertake the room acoustic measurements.

6.1 Measurements results - Unoccupied room

The results are presented for two sound sources locations (S1 and S2) as mid frequency average for T30 (Fig.16), EDT (Fig.17) and C80 (Fig.18). The two number shown for each receiver represent the parameter measured with Source 1 and Source 2 respectively.

6.2 Occupied room

Occupied measurements have not been undertaken in the different configurations. To understand how, in average the

Reverberation Time changes with different level of occupancy a CATT model has been used instead.
The average octave band performance is presented (Fig.19) for the following cases:

- Unoccupied room – result from measurements
- Simulated unoccupied room
- Simulated Occupied room music scenario (600 seats)
- Simulated Occupied room speech / assembly scenario (1000 seats)

7. DISCUSSION-CONCLUSIONS

7.1 Subjective Evaluation – Listenign tests

Alongside acoustic modelling and measurements, a subjective evaluation / listening of the hall has been done during performances and rehearsals, mainly of the Oxford Philarmonic Orchestra from different seats across the hall.

Listening tests have occurred during chamber music rehearsals or concerts. During the listening tests the ensamble was composed of 20-30 musicians mainly located in the centre of the hall in front of the stage. In this configuration all the loose seats are removed from the hall.

Sound reflections from the concave walls provides, at the rear of the hall, reflections in the 10-15ms after the arrival of the direct sound.

The rear part of the stalls and first balcony sound louder than what one would expect in a comparable sized shoebox room. The reflections from the side walls seem to increase the perceived source width. Reflections from the rear wall and balcony ceiling are perceivealbe and increase the sense of envelpment.

The lateral fraction has not been measured but only calculated with CATT and it shows that at the two ends of the hall an increase of this parameter could justify the high sense of envelopment.

From a frequency response point of view, the sound feels warm and reach in bass. Despite the reduction of reverberation time at lower frequencies (Fig 19), this could be associated to the fact that the wall scattering has an effect mainly at mid and high frequencies reducting the intensity of the reflections, on top of that there could be low frequencey effects that are not detectable with a ray tracing modelling.

The effect of the focus as a separate contribution to the aural experience is, due to the short delay, not detectable as a separate echo but the focusing effect is perceived as increase loudness. Compared to the simulation where the raytracing approach indicates precise spots where the focus happens, it sounds as if the focusing sweet spot would occupy a much bigger area and as such all the seats at the rear of the hall sounds similarly.

7.2 Conclusions and Further Studies

The oval design of the Olivier Hall and the analysis undertaken shows that the possible detrimental effect of concave surfaces is linked to the geometrical relationship between the source / audience location, surface finish and arrival time of reflections.

What is the effect of focusing in the specific case of the Olivier Hall?

Among all the concave walls, the only surfaces that seem to provide focus are the stalls rear walls. This is mainly perceived as an increased loudness, source width and overall envelopment at the rear of the stalls. The focusing does not create echoes and in general image shifting effect are not audible.

As expected, the room has carachter and not all the seats have the same sound. The geometric relatioonship between each seat with the source location on stage and location of sound reflecting surfaces changes across the hall, resulting in a wider range of subjective experience, if compared to a shoebox hall.

Despite this, the hall provides a good clarity, loudness and sufficient reverberation.

The hall is used not only by the school orchestras but regularly by the Oxford Philharmonic Orchestra and other professional ensembles for public performances. Subjective feedback from users, technician and musicians is positive and the hall is regarded to have a good acoustic for unamplified music and amplified sound events.

Understandably, due to its overall size, the room is too loud for full orchestra performances.

Further studies should include a wave-based analysis approach to evaluate the room effect also at low frequency.

8. FIGURES

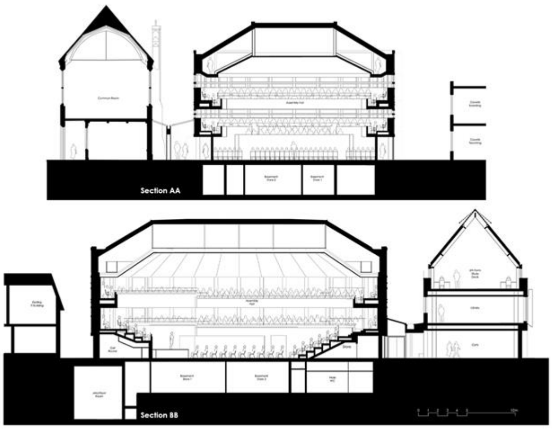


Figure 1. Olivier Hall short and long section showing the hall layout and relationship to other building on site.

Figure 2. Fixed seats.

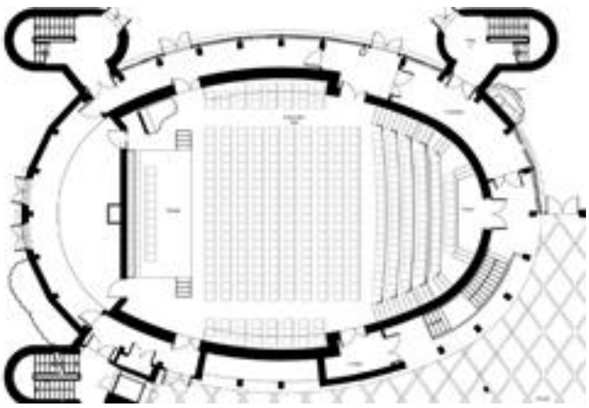


Figure 3. Hall oval plan arrangement – Stalls Level

Figure 4. Side walls with air diffuser (darker areas).

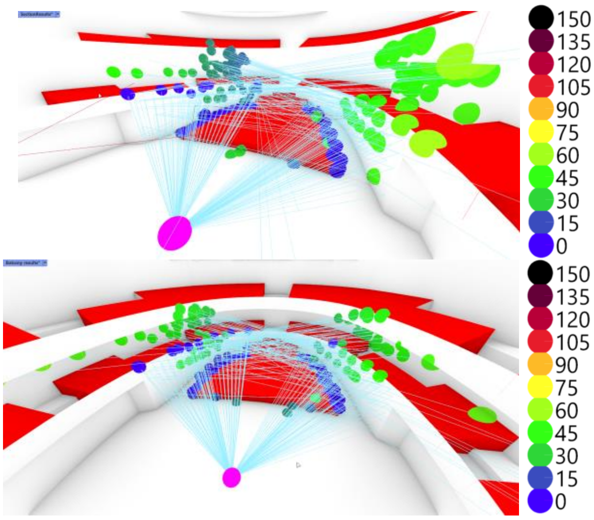
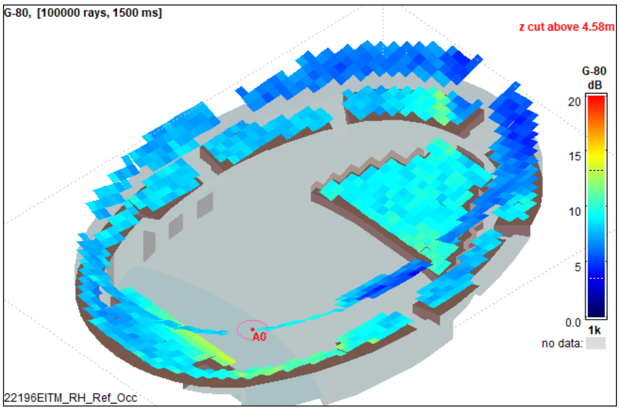


Figure 5. Focusing effect caused by rear stalls concave walls from Stage Right and Centre Stage sound sources. Reflections delay indicated in (ms).



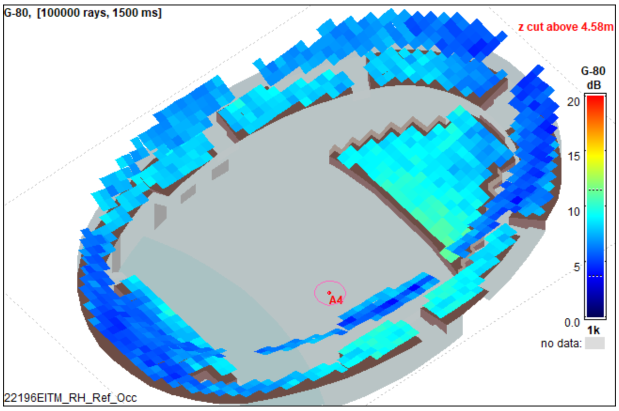


Figure 6. Catt Early Strength (G80 @1kHz) distribution from two sound sources.

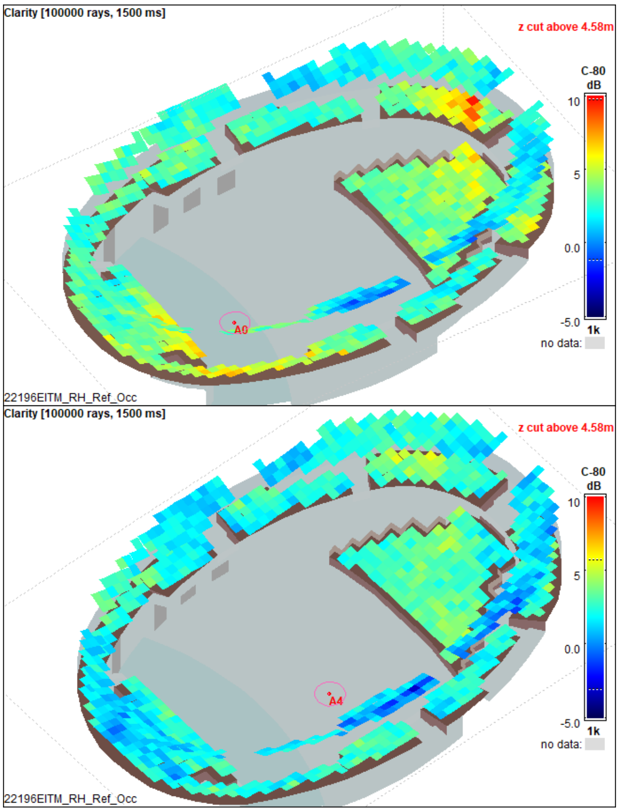


Figure 7. CATT Clarity (C80 @1kHz) distribution map from two sound sources.

Figure 8. Timber battens installed on side walls to provide scattering and reduce focusing at mid and high frequencies.

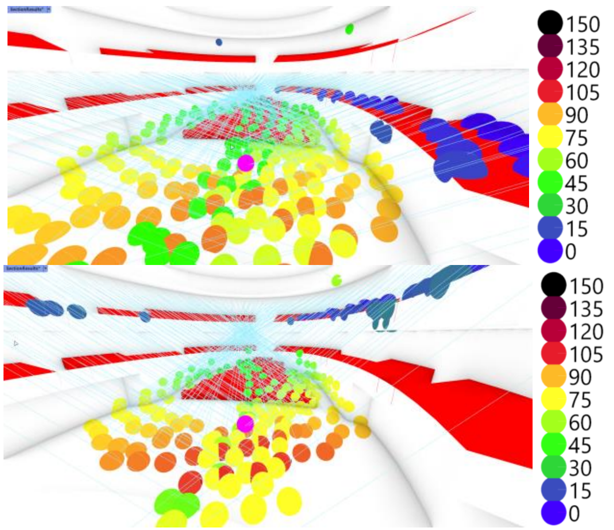


Figure 9. Second order reflections from first and second balcony perimeter wall and ceiling. Reflections delay indicated in (ms).

Figure 10. Perimeter wall at balcony level with columns protruding into the space

Figure 11. View of the oval sound transparent ceiling.

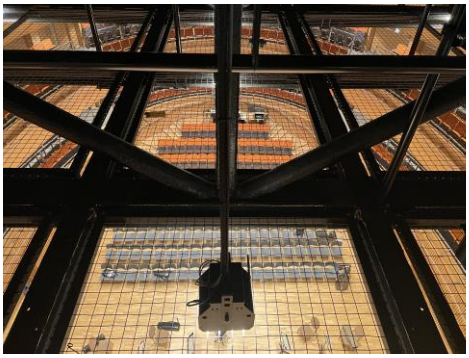


Figure 12. View through the tension wire grid

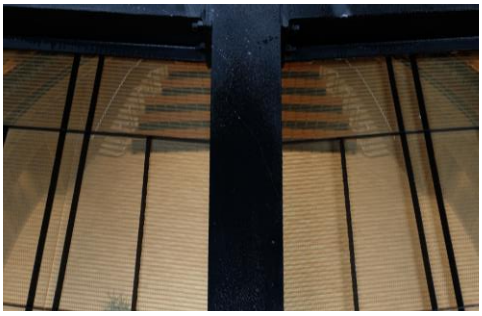


Figure 13. View through the open weave steel mesh

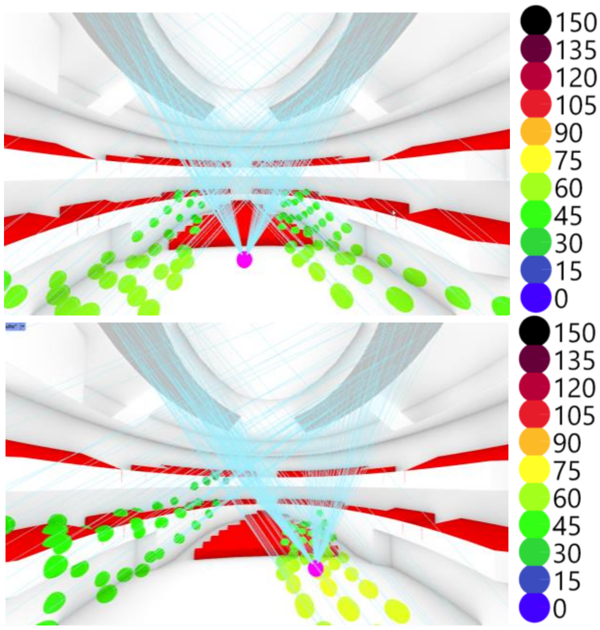


Figure 14. Overhead reflectors – 1rst reflection order. The sound reflectors located ~10-11m above the stage are at an angle and with an elliptic arrangement and have vertical angle ~ 40deg. Reflections delay indicated in (ms).

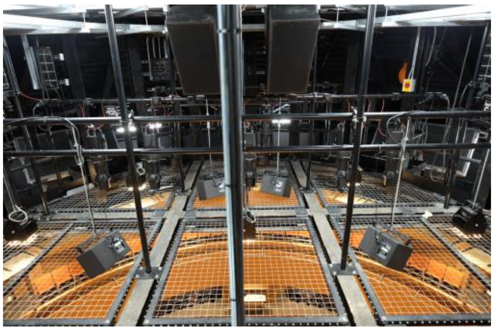


Figure 15. Technical level above the sound transparent ceiling.

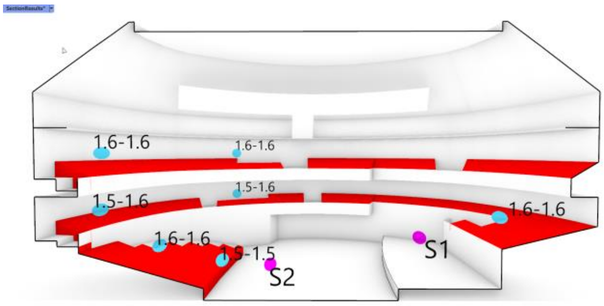


Figure 16. Measured mid frequency Reverberation Time T30 (s)

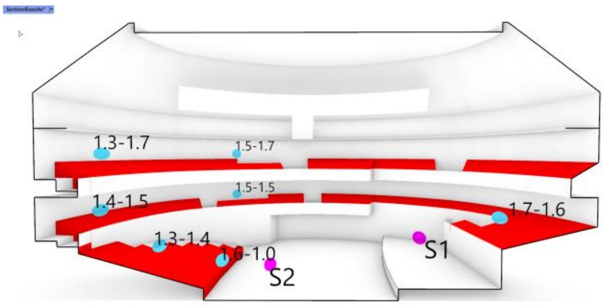


Figure 17. Measured mid frequency Early Decay Time EDT (s)

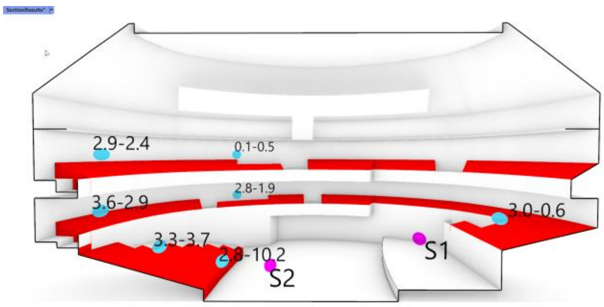


Figure 18. Measure mid frequency Clarity C80 (dB)

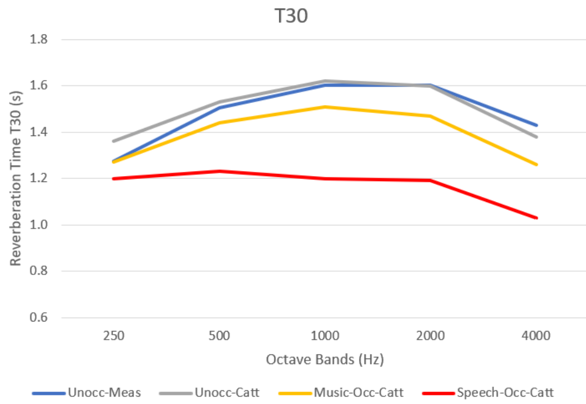


Figure 19. Reverberation Time T30 (s)

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