Auralisation and Analysis of the Star Wars Jedi Council Chamber

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***Abstract*—A model of the Jedi Council Chamber from the Star Wars Saga has been created in SketchUp to investigate the true acoustics of the room. Odeon was used to create several virtual impulse responses (IRs) for this space, utilising a hybrid geometric modelling method. These IRs were then convolved with anechoic recordings to create auralised sound sources for better analysis of the room's characteristics. Analysis of the IRs' acoustic quantities reveal that this space is not optimised for holding meetings. Possible reasons for this finding are that the room was not designed with consideration for acoustics, or additionally that the space may differ from how it appears, structurally or in regards to material composition.**

I. Introduction

Star Wars is a film franchise that is now regarded as a pop culture classic. The first film, Star Wars: Episode IV – A New Hope, was released almost 50 years ago, yet there are still new films, comics, and TV series being released to this day [1][2]. The Jedi Council Chamber is a room of particular note, with its eccentric chairs and large windows that overlook the planet Coruscant, the centre of the intergalactic Republic government. Many recall the scene in which Anakin Skywalker is denied the rank of master in this room but few question how it would have truly sounded [3]. As immersive as the film experience is, it is important to remember that most scenes are recorded on film sets, therefore the Jedi Council chamber is a space that has never truly existed. Instead, post-production would have been used to spatialise sounds and voices in a way that seemed appealing and correct to the sound designers of the film.

This report describes the process of modelling the chamber in SketchUp, then using Odeon to produce binaural and ambisonic impulse responses (IRs) for the space. Next, the recording of the anechoic sound sources is described, followed by the auralisation of these sources via MATLAB. Finally, the resulting files are analysed and conclusions are drawn.

Fig. 1. Qui-Gon Jinn and Obi Wan Kenobi standing before the Jedi council in Star Wars: Episode I - The Phantom Menace [4]

II. Room Modelling and IR Design

A. Modelling in SketchUp

As the chamber was destroyed and rebuilt multiple times throughout the timeline of the Star Wars universe, this project will focus on the version that was rebuilt 1000 years before the battle of Yavin (BBY), later destroyed by the rebellion in 19 BBY, visible in in the Star Wars prequel trilogy, episodes I, II and III [1][2]. It is pictured in Figure 1.

In order to create a model of this space, several pictures were collated and used as references to ascertain the room's size, shape, and the arrangement of internal structures. There are 12 Jedi council members in total, thus there are 12 chairs. There are also three different types of chair to account for the differences in physique between members. The room is fundamentally cylindrical however the windows, pillars, and door cause the room to be more angular. Therefore the space is effectively pentagonal with 4 windows, 5 pillars, and a door. This shape is best visible from above, as in Figure 2. An alternative, wire-frame view of the model is provided by Figure 3. As the ceiling is never visible in the films, a flat plain has been used, 8m above the floor.

Following this visual analysis, the room was modelled in SketchUp 2016 [5]. The chairs were

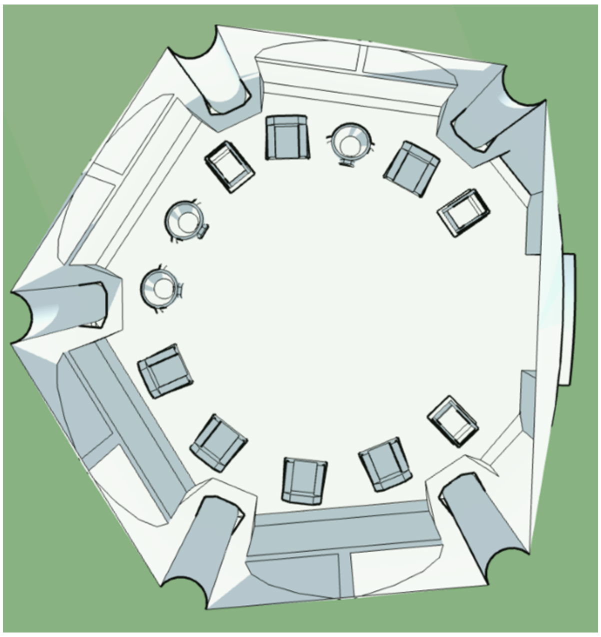

Fig. 2. An aerial view of the model created within SketchUp.

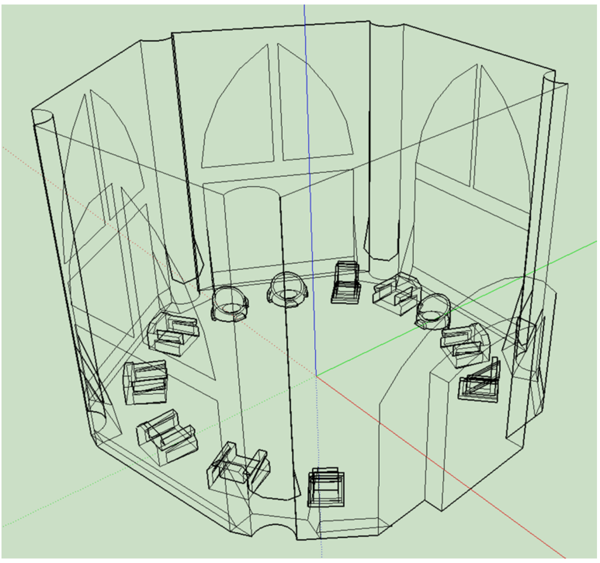

Fig. 3. An wire frame view of the model created within SketchUp.

modelled from observations, scaled to match character sizes and the size of surrounding objects. For example, as Mace Windu, played by Samuel L. Jackson, is 189 cm tall, using forensic estimations it was possible to calculate his tibial length to be 53.6cm ±3.27, thus his chair's seat is approximated to be 30cm from the ground [6][7]. The door size was estimated to be 3.5m, using a shot of Anakin entering the room [8], and the documented fact that he is 188cm tall. The window dimensions were estimated from a screenshot from a trailer for the upcoming Star Wars game, Eclipse, in which Yoda, who is 61cm, stands next to the window [1][9].

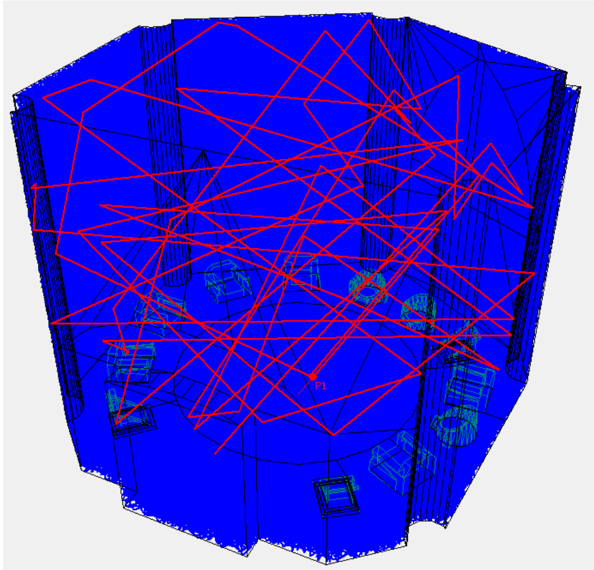

Fig. 4. Screenshot of the space after water tight testing with 4000 rays.

B. Creating IRs in Odeon

1) Water Tight Testing: Before generating the IRs, the water tightness of a space must be verified to check that it is fully enclosed. This means that there are no missing or warped surfaces, none of the outer surfaces are transparent, and all of the sources are located within the room. To do this, as recommended by Odeon, a source was placed in the centre of the room, and all surfaces were set to rough concrete as it did not matter as long as they were not fully absorbent or transparent. Within "3D Investigate Rays", the system was set to 'Free Run', and allowed to generate 4000 rays in random directions emanating from the source point. As none of these rays escaped the confines of the model, pictured in Figure 4, this process successfully confirmed that the room is watertight [10].

TABLE I
LIST OF MODELLED MATERIALS AND PROPERTIES.

Material Description	Object Type	α(w)	Most Absorption
Smooth concrete, painted or glazed	Chair exteriors, walls	0.05	High frequencies
Marble or glazed tile	Floor, ceiling, pillars	0.00	High frequencies
Large panes of heavy plate glass	Windows	0.05	Low frequencies
Heavily upholstered concert hall chairs	Chair padding	0.85	Mid frequencies

2) Setting Materials: In total, this model has 1,139 unique points forming 983 different surfaces, all of which were assigned an acoustical material to model absorption. Fortunately, reference images indicate a limited range of materials used for the room, thus this process was not too laborious. A list of the chosen materials and some of their absorption properties are available in Table I. A more detailed table listing all material absorption coefficients across frequency bands can be found in **??**.

The walls and harder exteriors of the chairs seem to be made from the same grey, slightly shiny material, which was thought to be a smoothed or glazed rock, therefore smooth concrete was chosen as its real-world representation. As the seats themselves are well-padded, the absorption values for heavily upholstered chairs were chosen to capture the room in an unoccupied state. The floor is clearly made of a marble or marble-like material, thus marble was chosen for this surface and also for the ceiling. The metallic pillars were the hardest material to match as there was no real-world equivalent within the Odeon materials library, thus marble was also chosen as it seemed the most suitable.

The absorption values provided for each frequency band of materials suggest that the room will mostly absorb high frequencies. As the windows take up a large amount of surface area, it is likely that many low frequencies will be absorbed too. However, despite being highly absorbent, the seat padding does not take up a large amount of area within the room, therefore it is likely that many mid frequencies will remain. When combined with the size of the room, it is possible that this may result in a ‘muddy’ sound.

TABLE II
LIST OF IR SOURCE AND RECEIVER POSITIONS.

IR #	Source Position	Receiver Position	Track #
1	Centre	Right side seat (Yoda)	5, 6
2	Beam chair on door left	Centre	15, 16
3	Rear large chair	Big chair on door left	25, 26
4	Doorway	Back small chair, right side	35, 36

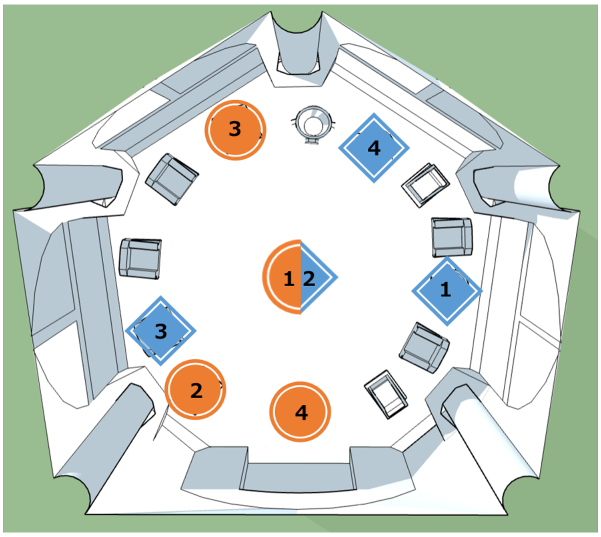

Fig. 5. Positioning of sources and receivers for each IR, represented by circles and diamonds respectively.

3) Executing Job List: Odeon’s method for generating impulse responses is a geometric hybrid between image-source method (ISM) and a ray tracing algorithm. For early reflections, ISM and early scattering method is used, whilst ray radiosity is used to model late reflections. This system further frequency dependently models source directivity, surface absorption, and air absorption [11].

ISM uses representations of the source mirrored across surfaces to model reflections [12]. As the number of source images to be modelled will increase exponentially with increased reflection order number, this is limited to early reflections only. Even 100 surfaces modelled at reflection order 2 results in 10,000 image sources however, as some of these points may be unreachable in the specified reflection order, Odeon initially uses specular ray tracing to determine which surfaces are reachable within the order limit. This reduces processing time required as not all image sources will be relevant. Odeon will then evaluate each image source position to establish which are possible then add them to the final output [11].

Following this, secondary sources are generated along the surfaces on which the source is found to reflect. These sources produce rays with Lambert directivity, meaning that they follow Lambert’s cosine-law dictating that cosθ is proportional to the intensity of scattered sound [13]. These rays will only reflect for the remaining order of reflections, and in a specular fashion, e.g: if the reflection order is 3 and the surface’s image source occurs after one reflection, then the outbound secondary source ray will reflect twice. A further secondary source is then added only at these points of reflection, that behaves in the same fashion [11].

Unlike traditional ray tracing which uses a detection sphere to determine when rays have returned to the source position, Odeon uses ray radiosity to model the late reverb tail. Initially, a ray will be emitted and reflect off of the first surface in a random coefficient-weighted direction. Once the ray reflection order has exceeded the predefined early reflection order, subsequent reflections will produce secondary sources also with Lambert directivity. This ray will continue to propagate until it reaches the specified impulse response length. The number of rays is also specified by the user, the more rays that are fired, the more accurate the IR will represent the space. Once all rays paths have been modelled, late secondary sources that are visible to the receiver are added to the output [11].

4) Source and Receiver Positions: According to the ISO 3382 standard on recording the IRs of a space, there are certain considerations that should be made when placing sources and receivers [14]. Sources should be omnidirectional, at least 1.5m apart from the receiver, and 1.5m above the floor. A minimum of two sources should be placed in expected sound source locations. Receivers should also be omnidirectional and placed with the aim to capture the entire space at expected listener locations, for example a height of 1.2m is recommended to represent seated audience members. They should be placed at least 2m apart and 1m away from any reflective surfaces, including the floor.

Several source and receiver positions have been chosen to give a broad yet accurate impression of the space as it would be experienced by council members and visitors. These are detailed in Table II, and Figure 5. To comply with the ISO 3382 standard, all sources are 1.5m above the ground plane. Receiver positions are 1.2m to emulate a seated council member, with the exception of receiver position 4, which is at 1.75m to mimic a standing listener position. Additionally, the doorway position is at least 1.5 metres away from any wall surface.

5) Room Setup: The room setup was set so that 100,000 stochastic rays would be fired with

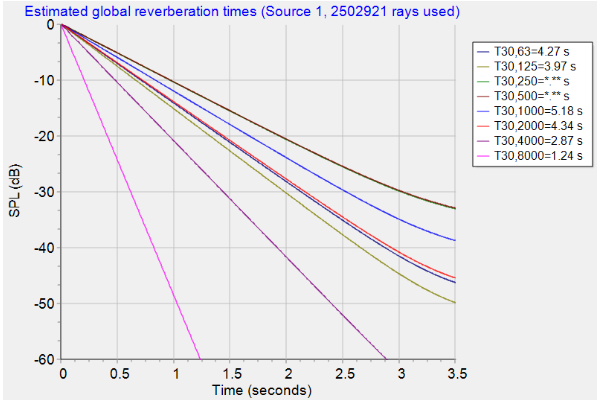

Fig. 6. Estimations made in Odeon of the T30 across different frequency bands, performed with 2.5 million rays.

an impulse response length of 6 seconds. This ray value was chosen as it gave sufficient definition to the IR with fewer audible artefacts than lower ray values. The IR length was chosen as initial particle tracing testing performed within Odeon revealed a T30 values of ranging between 1.24 and 5.18 seconds across octave bands, see Figure 6 [11]. As the capture is performed virtually, there is no need to add the recommended additional 5 seconds to the end of the recording to account for background noise [14], especially as this would increase the processing time required. Instead the impulse response length was chosen by adding 15% to the highest estimated time value. The temperature has been set to 20 degrees Celsius and the humidity to 50%. Each job generates both a binaural impulse response file, and a B-Format file for each source and receiver combination specified.

The transition order has been set to 3, meaning that reflections up to third order will be modelled using the aforementioned early reflection algorithms, whilst fourth order and above will be modelled as late reflections. This is because the processing required for early reflections grows exponentially with increasing order, and would be especially burdensome for a space with almost 1000 surfaces.

Once obtained, the channel order for each B-format file was converted from FuMa (WXYZ) to AmbiX (WYZX) in MATLAB. Table II provides the number listings for the obtained room impulse responses in the track list, Table IX, located in the Appendix of this report, containing the names for each file.

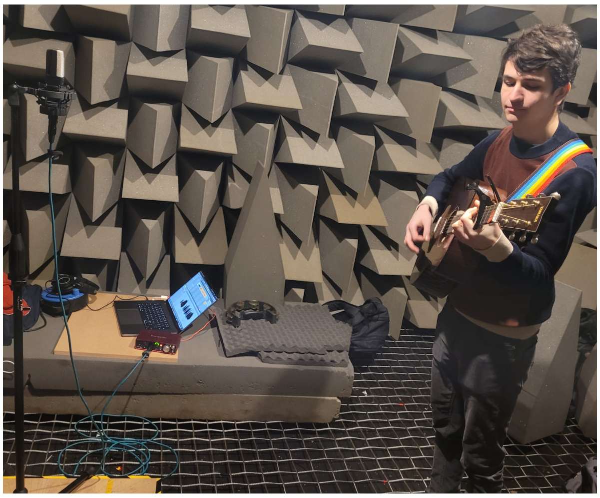

Fig. 7. Set up and positioning for guitar recording within the anechoic chamber.

III. Anechoic Recording Description

Several recordings were made in the anechoic chamber at the University of York. They were captured using an AKG C414 and a Focusrite 2i2 into Ableton Live on a Macbook Pro. In order to avoid colouration caused by the proximity effect, the microphone was set to record omnidirectionally. The overall spectrum for this setting is also flatter in response overall [15]. Additionally, the microphone was set to a 80Hz low pass filter as there was some energy in the room caused by a generator close to the building. All sources were recorded approximately 1.5m from the microphone to obtain a balanced capture of the instrument performances.

For the speech sample, the Spanish tongue twister "Tres tristes tigres tragaron trigo en un trigal" was recorded to assess clarity of the space as this sentence features an elevated amount of transient sounds due to the repeated 't' sound. A set of guitar chords has been recorded to assess the musical definition and additionally clarity across a broader spectrum. The set up for this recording is pictured in Figure 7. A short rhythmic extract on the tambourine was recorded to access the definition for more percussive instruments. A recognisable rhythm was used for this to make any degradation in rhythmic definition more obvious than an arbitrary pattern [16].

Finally a flute was chosen as it is a typical instrument for concert halls, thus it would be interesting to see if the space is better suited to being a concert hall to a meeting space. The piece chosen was the prelude to Suite Antique by John Rutter [17]. It contains both shorter and longer transitions between notes, allowing for better assessment of how the space may augment or impair the musical performance.

The file names for all anechoic recordings are located in entries 1-4 of the track list in Table IX of the Appendix.

IV. Auralisation of the Modelled RIRs with Anechoic Recordings

Auralisation of the anechoic recordings with each of the IRs was performed in MATLAB R2021B [18]. A full track list of the auralised files produced can also be found in the Appendix in Table IX. A function in MATLAB was used to convolve and generate each of these files. A flowchart demonstrating the signal flow of this script is pictured in Figure 8.

It works as follows: both the anechoic and IR file are loaded into MATLAB and compared to ensure their sampling frequencies match. Next, the number of channels for the IR audio file is determined, and the final sample length of the convolved file is calculated by adding the lengths of both audio files then subtracting one. In a for loop, the first output channel is then created by multiplying the frequency representation of both files with each other in a samplewise fashion, then taking the inverse frequency representation of the resulting array. This is done as, according to convolution theorem, multiplication in the frequency domain is equivalent to convolution in the time domain [19]. The same process is applied to the remaining channels. Once all channels are convolved, the entire array is normalised and output to a WAV file.

V. IR Analysis and Discussion

A. IR Parameters

Before analysis, it is important to establish and define the parameters that will be focused upon. RT60 is one of the best known features of an impulse response, coined by Sabine as the time taken for a sound to reach one millionth of its direct intensity. For a concert hall, this would be between 2-2.2 seconds, whilst for a lecture theatre, it would be just under 1 second [20]. It can be calculated using Equation 1, where V is the space's volume, S is its effective surface area,

Auralisation Process of Anechoic files with IRs

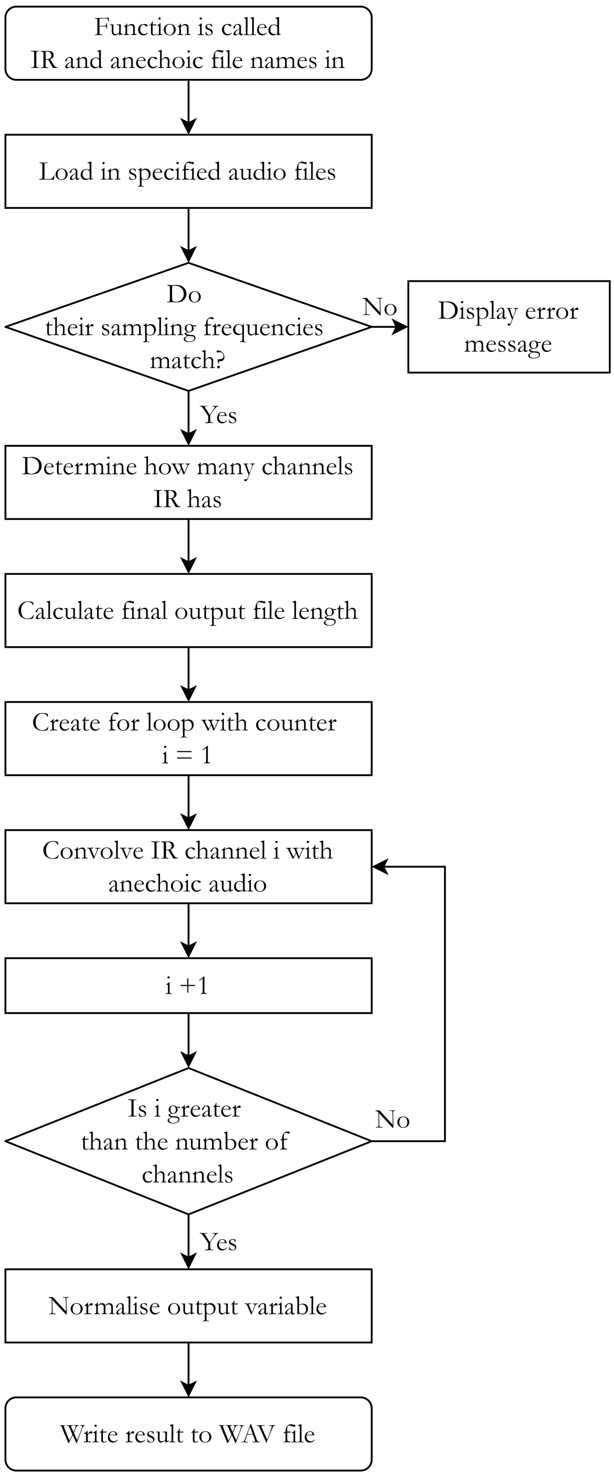

Fig. 8. Auralisation process of anechoic recordings within the modelled room.

and α is the absorption coefficient [21].

$$RT60 = \frac{0.161V}{S\alpha} \quad (1)$$

Equation 2 is a rough estimation of the space's RT60, made under the assumption that the space is a regular pentagonal prism with singular materials for each surface and no internal structures. Taking the side length to be 5 metres, gives a volume of 344.1m^3 [22]. The effective surface area is then calculated to be 200 multiplied by 0.05, the weighted absorption coefficient of the windows and walls. As the average coefficient of the floor and ceiling is reported to be 0, they will be ignored.

In total, this gives an estimated RT60 of 5.54 seconds. In reality, this value will likely differ from the actual RT60 due to the assumptions made however, it allows for some rough expectation of how long the decay time should be.

$$\frac{0.161 \cdot 344.1}{((5 \cdot 5 \cdot 8) \cdot 0.05)} = 5.54 \text{ seconds} \quad (2)$$

However, this measurement does not fully describe the differences between spaces. The ISO 3382 standard lists some alternative qualities to be measured for the analysis of IRs. A similar measurement that can be used to obtain decay time is the T30, determined by extrapolating the value at -60dB based on the trajectory between -5 to -35dB. This is done to counter the effect that background noise may have on the IR signal. The early decay time (EDT) is a similar measure, however this is obtained from the slope between the points 0 and -10dB. It is subjectively perceived as the reverberance of a space. For a typical concert hall, the average range of this value is typically 1 to 3 seconds [14].

D50 is defined as the early to total energy, allowing for a better idea of syllable intelligibility of a space as early reflections support speech. The equation to calculate this value is featured in Equation 3, where p is the room's sound pressure. Its average range is 30-70%. C80 is similar to the previous, except it measures the early to later arriving energy ratio. This parameter is useful in gauging how appropriate a space is for musical content. Its formula is very similar, featured in Equation 4, returning a dB value. On average, its range is ±5dB. Both of these measures correlate with the perceived clarity of sound [23].

$$D_{50} = \frac{\int_0^{50\text{ms}} p^2(t)\,dt}{\int_0^{\infty} p^2(t)\,dt} \tag{3}$$

$$C_{80} = 10log\frac{\int_0^{80\text{ms}} p^2(t)\,dt}{\int_{80\text{ms}}^{\infty} p^2(t)\,dt} \tag{4}$$

As IRs are not uniform across the frequency spectrum, in order to build a more complete impression of the space, these mentioned parameters should be measured across different frequency bands. To do this, the W channel for each IR position was fed into a provided toolbox in MATLAB to obtain the mentioned quantities across octave bands 63Hz, 125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, and 8000Hz. A separate script was also used to obtain a graphical representation of each position's spectral content.

B. IR Analysis

C. IR Position 1: Centre to Right Side Seat (Yoda)

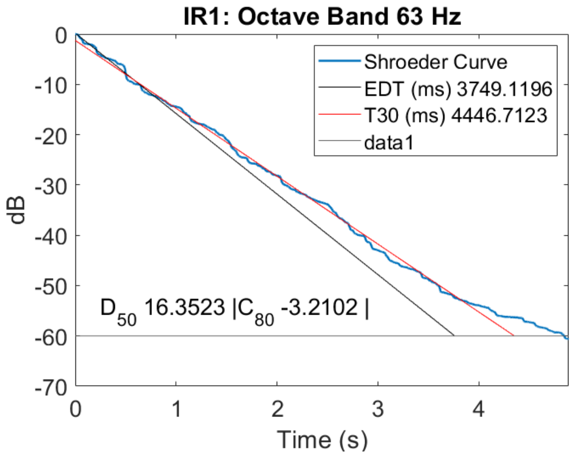

Fig. 9. Schroeder curve of 63Hz octave band for IR position 1 with T30, EDT, C80, and D50 values.

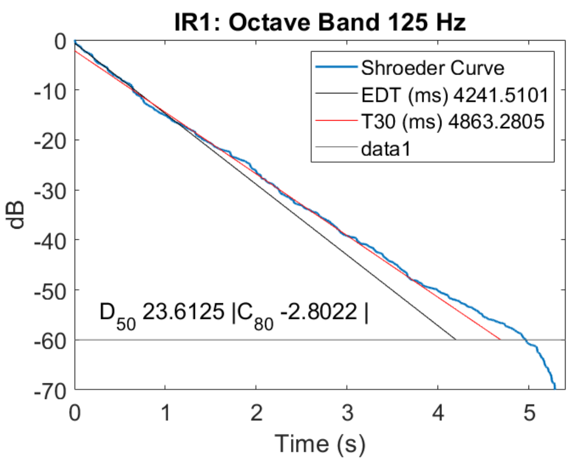

Fig. 10. Schroeder curve of 125Hz octave band for IR position 1 with T30, EDT, C80, and D50 values.

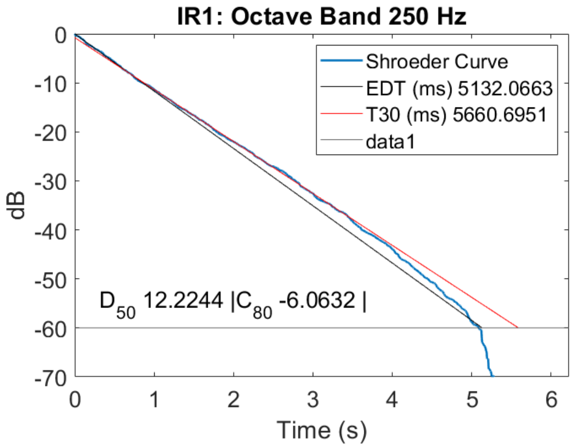

Fig. 11. Schroeder curve of 250Hz octave band for IR position 1 with T30, EDT, C80, and D50 values.

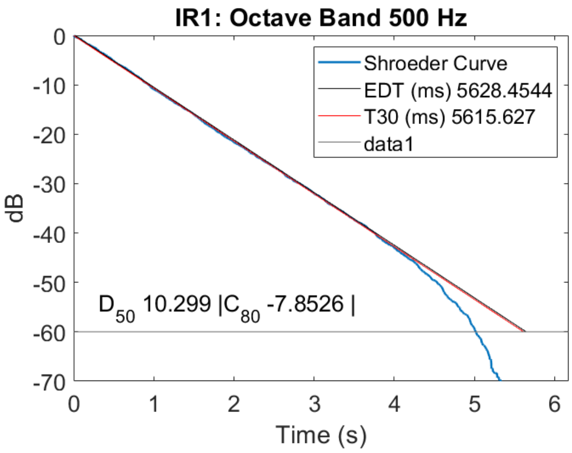

Fig. 12. Schroeder curve of 500Hz octave band for IR position 1 with T30, EDT, C80, and D50 values.

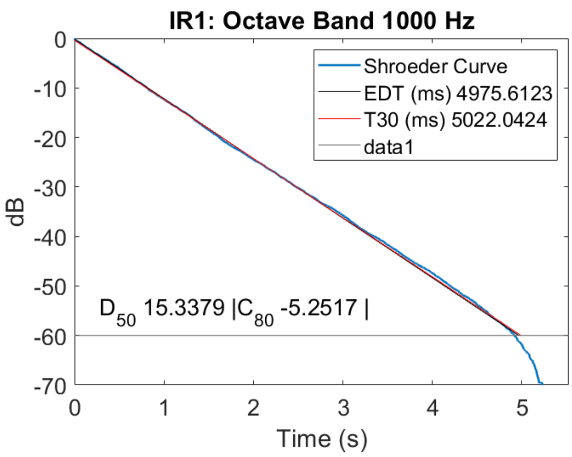

Fig. 13. Schroeder curve of 1000Hz octave band for IR position 1 with T30, EDT, C80, and D50 values.

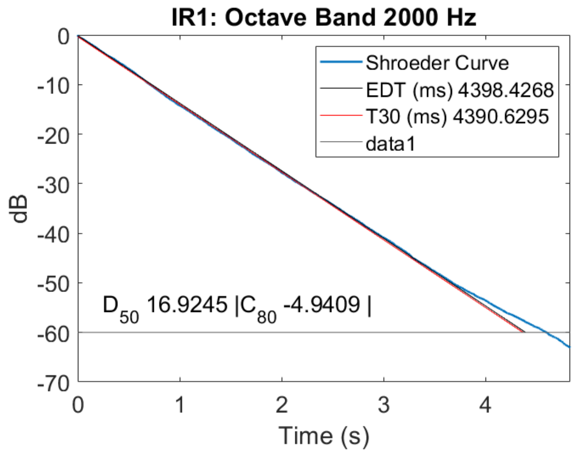

Fig. 14. Schroeder curve of 2000Hz octave band for IR position 1 with T30, EDT, C80, and D50 values.

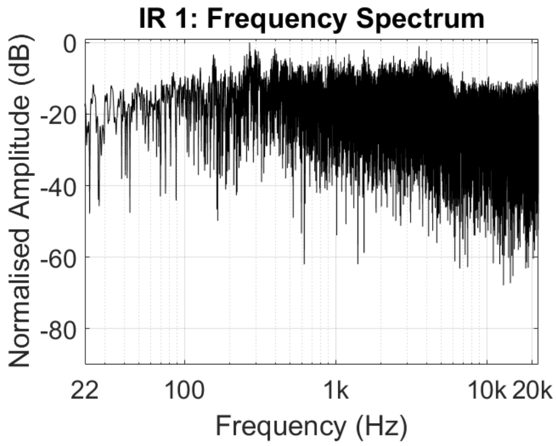

Fig. 17. Frequency Spectrum representation of IR position 1.

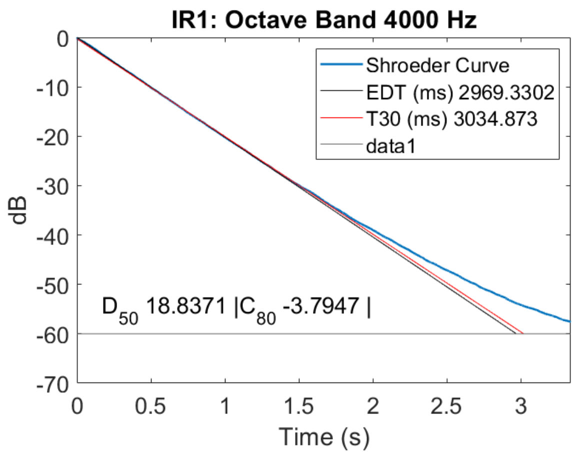

Fig. 15. Schroeder curve of 4000Hz octave band for IR position 1 with T30, EDT, C80, and D50 values.

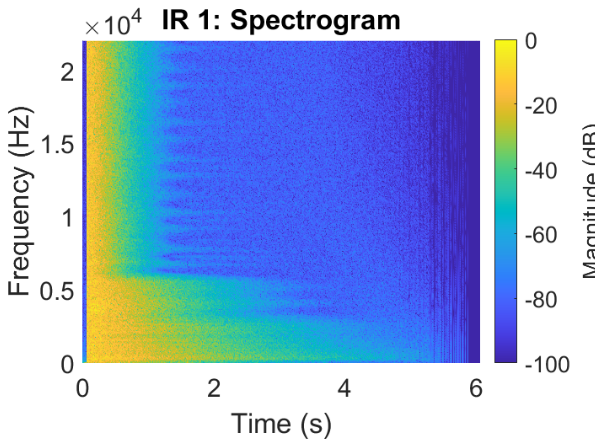

Fig. 18. Spectrogram representation of IR position 1.

D. IR Position 2: Beam Chair on Door Left to Centre

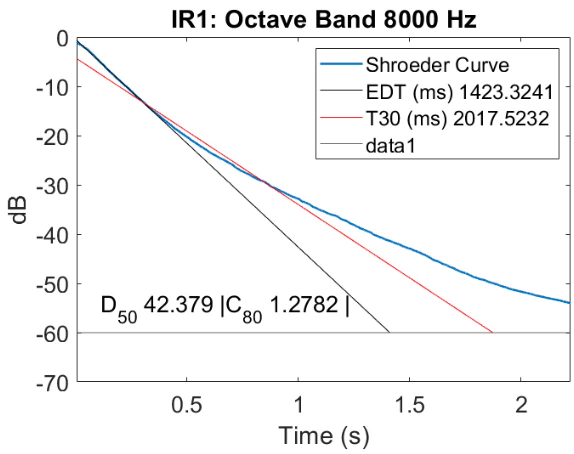

Fig. 16. Schroeder curve of 8000Hz octave band for IR position 1 with T30, EDT, C80, and D50 values.

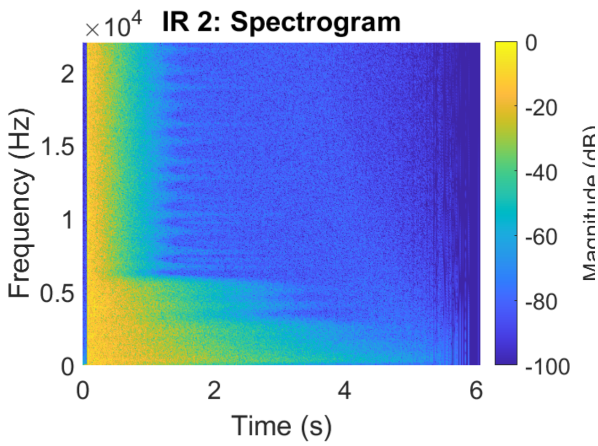

Fig. 19. Spectrogram representation of IR position 2.

E. IR Position 3: Rear Large Chair to Big Chair on Door Left

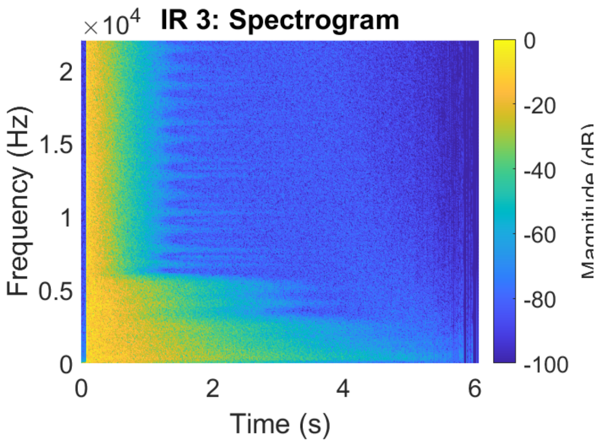

Fig. 20. Spectrogram representation of IR position 3.

F. IR Position 4: Big Chair on Door Left to Doorway

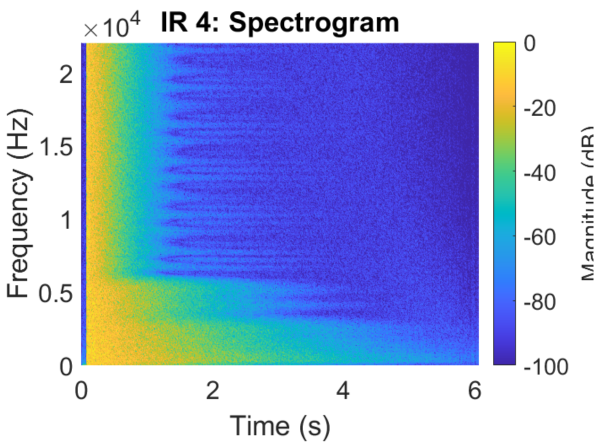

Fig. 21. Spectrogram representation of IR position 4.

TABLE III
QUANTITY VALUES AVERAGED ACROSS 500 AND 1KHZ OCTAVE BANDS FOR EACH IR POSITION.

Quantity	IR 1	IR 2	IR 3	IR 4	Range
T30 (ms)	5318.8	5313.9	5379.2	5242.1	137.0
EDT (ms)	5302.0	5182.9	5045.9	5137.5	256.1
C80 (dB)	-6.55	-4.91	-5.95	-4.96	1.64
D50 (%)	12.82	18.03	15.28	18.44	5.62

G. IR Discussion

Before analysis, listening to the IRs alone, it is clear that this room sounds much larger than it does in the films. In fact is sounds closer to a church hall, most likely due to the room materials and the apparent lack of acoustic treatment. This would certainly cause problems for conducting meetings in this space as there would be a great loss in speech intelligibility.

It is important to note that the chamber is primarily symmetrical, with the largest irregularity being the placement of the chairs. As a result, the IRs show high resemblance between positions and so the auralisations for each also closely resemble each other. This is clearly seen between Figures 18, 19, 20, and 21, where all graphs display a near identical energy distribution and decay irrespective of positioning. There are, however, some minute differences between frequency responses. One reason for the differences in sound between IRs is that in different positions, surface reflections will arrive at different times. Additionally, differing proximities to walls or windows causes slight changes in the absorption of high and low frequencies respectively.

As the results for each position are largely similar, only the Schroeder curve graphs for IR position 1 are presented in this report, see Figures 9 - 16. These graphs also present the T30, EDT, C80, and D50 values for octave bands between 63Hz to 8000Hz. The values of each of these quantities for all IR positions and octave bands are available in Tables V - VIII within the Appendix. These values have also been averaged across frequency bands 500Hz and 1000Hz for each IR position in Table III to obtain singular values for each quantity.

The quantities obtained from this more in-depth analysis reveal that the IRs are indeed different however, perceptually they are very similar. According to ISO 3382, the just noticeable difference (JND) for EDT is 5%, and averaged values for this quantity differ at most by 5.08% between IRs positions 1 and 3. Additionally, for D50, the JND is 5% which is achieved between positions 1 and 2 (5.21%), and 1 and 4 (5.62%). Additionally, for C80, there is a difference of 1.64 dB between IR 1 and IR 2, 1.59 dB between IR 1 and IR 4, and 1.03 dB between IR 2 and IR 3 therefore subjective clarity should differ between these positions as they slightly exceed recorded the JND boundary [14]. A reason for IR 1 being the most different position may be that it is that the source position is the furthest away from the walls or windows. IR positions 2 and 4 are the most similar to each other, this is likely due to them originating from similar positions of them room.

As this space was designed for meetings, ideally its RT60 should not exceed that of a lecture theatre, which is idealised by Sabine as being under 1 second [20]. However, in reality, T30 values range between 2.83 and 5.63 seconds, with the shortest values towards the higher end of the spectrum and their peak reverberant times around the 250Hz-1000Hz octave bands. This confirms the previous theory that the mid frequencies would be poorly absorbed by the room's materials. Despite the broad assumptions made in the estimation of the RT60 value using Sabine's formula, it seems that the value obtained was in fact not so far from the actual values exhibited by the virtual space. The values from Odeon's prediction are also relatively close to the measured values also although the high 8000 Hz band does not decay as fast as it anticipated.

The average EDT value of all IR positions exceeds the typical range by roughly 2.2 seconds. This means that the perceived reverberence of the space should actually be greater than that typically experienced in a concert hall. The magnitude of this value also implies that speech intelligibility will be impaired. The C80 average values are roughly 0.6dB below the typical range, whilst the D50 values are around 13.9% below the range. This suggests that the overall clarity and definition are below that of a typical concert hall. As the specific C80 values for positions 2 and 4 are just within the range, musical clarity should be slightly improved for these positions.

Clearly a major reason for these less than ideal values is that the room was designed with aesthetics in mind over practicality. As the audio for the films was to be processed in post production, the artists had much artistic freedom in their design of the room, without the need to consider the acoustical consequences of the room's design. However, the homogeneity between IRs does, in fact, support the originally architectural intent behind its design. In the film, all council members are to be thought of as of equal importance, thus granting them an equal acoustical experience regardless of position would support this sentiment [2].

VI. Auralisation Analysis and Discussion

A. Auralisation Discussion

Figures 22 - 29 display the spectrograms for each anechoic recording with the first IR position.

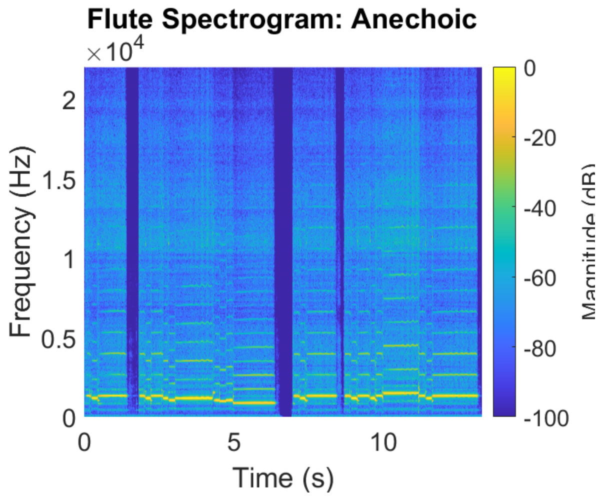

Fig. 22. Spectrogram representation of anechoic flute recording.

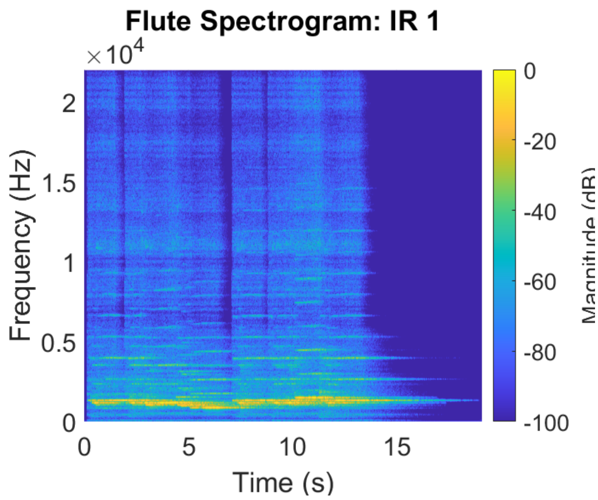

Fig. 23. Spectrogram representation of flute recording auralised to IR position 1.

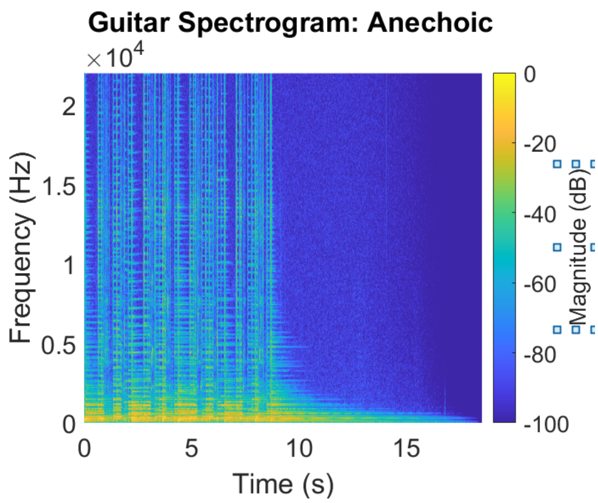

Fig. 24. Spectrogram representation of anechoic guitar recording.

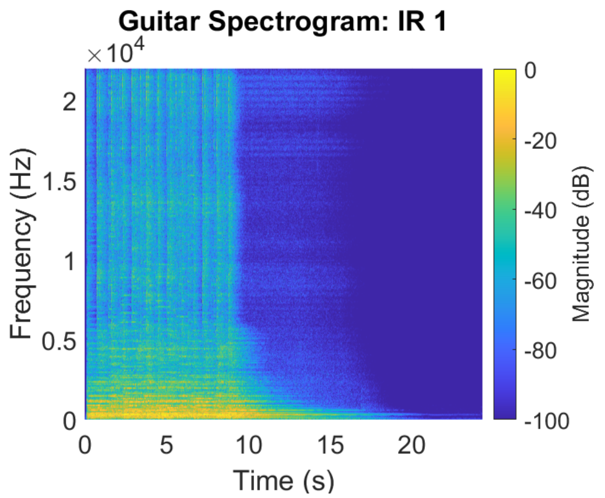

Fig. 25. Spectrogram representation of guitar recording auralised to IR position 1.

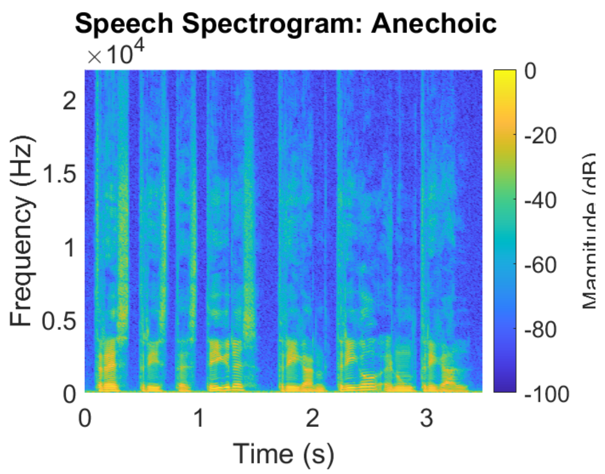

Fig. 26. Spectrogram representation of anechoic speech recording.

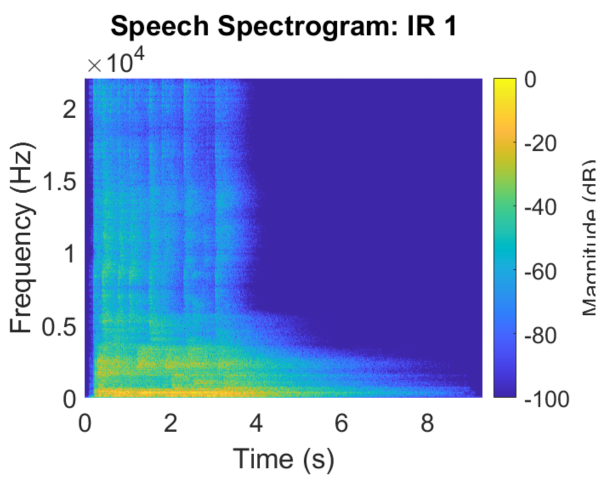

Fig. 27. Spectrogram representation of speech recording auralised to IR position 1.

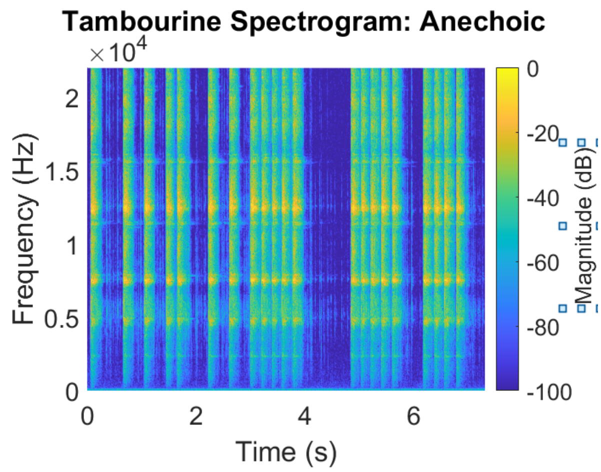

Fig. 28. Spectrogram representation of anechoic tambourine recording.

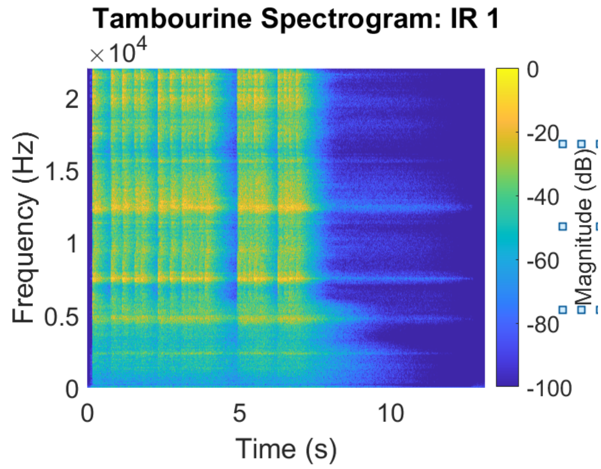

Fig. 29. Spectrogram representation of tambourine recording auralised to IR position 1.

As before, only the first position has been used as there is no large difference between positions. It is clear from these graphs and the audio files themselves that there is a considerable drop in clarity, which supports the findings from the IR analysis. This is most obvious between Figures 28 and 29. The gaps between tambourine hits become barely visible as the transients are temporally smeared. This smearing has also affected the harmonic instrument sources, such as the flute, as the successive notes bleed into each other, creating dissonance between the second intervals.

The auralisation of these recordings has also resulting in spectral filtration. This is most obvious in the guitar and flute spectrograms, Figures 22 - 25. There is an apparent reduction in frequencies above 500 Hz in the processed version of each with a slightly emphasised lower end. This corresponds with the spectrum graph and spectrograms for the IR position in Figures 17 and 18, also confirming that the auralisations have been convolved correctly.

Despite the mentioned dissonances, the space seems to best accommodate the solo flute as the held notes give the impression of suspense which was as not possible in the dead anechoic space. The guitar does not sound terrible in this space however, the lack of clarity does pose a problem, so any faster or more complex pieces may become more lost. Ironically, the speech is does not seem as well suited to this space as words bleeding into one another has lead to a loss in intelligibility. This implies that, in a meeting situation, council members would have to wait between speakers and talk slowly to remain understood which would not be very practical. Despite the smudged transients, the tambourine does remain fairly clear, however with a faster tempo or a drum kit as a source, clarity would most likely soon be lost.

VII. Limitations

From the description of the modelling process, it is clear that there have been certain creative liberties taken in the recreation of this room. There are no publicly available official blueprints for this room, so it is possible that the true size differs to the model. Additionally, as the ceiling of the room is not shown in films, it is possible for there to be some acoustic treatment that is not apparent in reference images.

As the genre of the film is sci-fi and the room itself is set on an alien planet, it would not be unreasonable for the materials of the room to be ones that do not exist, perhaps with far higher absorption than those used in Odeon. Furthermore, this room was captured as it would be in its unoccupied state, however with the council members present, absorption would increase, improving overall speech intelligibility.

It is also important to acknowledge that the IRs that have been generated for this project will fluctuate should the simulation be rerun, as ray-tracing methods do contain an element of uncertainty caused by the system and method itself [23]. The number of rays with which the IRs could be generated was also limited due to the system and storage limitations of the computer on which Odeon was running. Although it is not though that this extra detail would give significantly different results from those presented, it would increase the reliability and accuracy of the responses.

There is no real-world comparison, however, due to using geometric reverberation, the IRs most likely have more higher frequency content than reality and a poorer low frequency response. This is because it cannot emulate the nodes or standing waves of a room. For a better low response a hybrid wave-based reverb with ray tracing could be used, or even a wave-based reverb with high frequency compensation [24].

VIII. Conclusion

Software has been used to successfully model the acoustics of a fictional space. Auralisations make it evident that the space was not as well suited to purpose as sound designers may have made it seem in the movies however, there are also limitations to this model particularly as the film belongs to the sc-fi genre. An analysis within MATLAB has revealed that the acoustic quantities of this room make it inappropriate, not only as a meeting space, but also for concert hall purposes as it exceeds the typical range for clarity and perceived reverberation. Listening to the auralisations supports this statement for speech, however it does seem pleasant for listening to a solo flute performance. Although the space may not be perfectly designed for holding meetings, its design does allow for an equal experience between council members. Therefore, this space does satisfy its purpose to some extent.

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APPENDIX

TABLE IV
DETAILS FOR ABSORPTION ACROSS OCTAVE BANDS FOR EACH MATERIAL.

Material	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	α(w)
Smooth concrete, painted or glazed	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.05
Marble or glazed tile	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.00
Large panes of heavy plate glass	0.18	0.18	0.06	0.04	0.03	0.02	0.02	0.02	0.05
Heavily upholstered concert hall chairs	0.72	0.72	0.79	0.83	0.84	0.83	0.79	0.79	0.85

TABLE V
PARAMETER VALUES ACROSS OCTAVE BANDS FOR IR POSITION 1.

Quantity	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	Average	Range
T30 (ms)	4446.7	4863.3	5660.7	5615.6	5022.0	4390.6	3034.9	2017.5	4381.4	3643.2
EDT (ms)	3749.1	4241.5	5132.1	5628.5	4975.6	4398.4	2969.3	1423.3	4064.7	4205.1
C80 (dB)	-3.21	-2.80	-6.06	-7.85	-5.25	-4.94	-3.79	1.28	-4.08	9.13
D50 (%)	16.35	23.61	12.22	10.30	15.34	16.92	18.84	42.38	19.50	32.08

TABLE VI
PARAMETER VALUES ACROSS OCTAVE BANDS FOR IR POSITION 2.

Quantity	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	Average	Range
T30 (ms)	4202.7	4618.2	5584.0	5589.7	5038.0	4385.0	3057.2	2010.8	4310.7	3579.0
EDT (ms)	4928.9	4124.4	5588.0	5523.8	4842.0	4298.1	2847.6	1310.1	4182.9	4277.9
C80 (dB)	-3.29	-6.01	-6.06	-5.13	-4.70	-3.83	-3.21	2.67	-3.70	8.73
D50 (%)	15.13	14.89	15.94	18.91	17.14	19.86	21.92	50.33	21.76	35.44

TABLE VII
PARAMETER VALUES ACROSS OCTAVE BANDS FOR IR POSITION 3.

Quantity	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	Average	Range
T30 (ms)	4207.1	4568.3	5525.8	5654.9	5103.5	4425.8	3018.0	2000.8	4313.0	3654.1
EDT (ms)	4365.4	4873.3	5395.1	5072.3	5019.5	4234.0	2912.1	1358.7	4153.8	4036.3
C80 (dB)	-4.10	-3.35	-5.27	-7.98	-3.92	-4.13	-3.56	2.30	-3.75	10.28
D50 (%)	19.39	15.84	17.03	7.81	22.75	22.01	20.18	48.01	21.63	40.20

TABLE VIII
ACOUSTIC QUANTITY VALUES ACROSS OCTAVE BANDS FOR IR POSITION 4.

Quantity	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	Average	Range
T30 (ms)	3874.1	4472.5	5580.0	5456.7	5027.6	4408.0	3123.3	2032.8	4246.9	3547.2
EDT (ms)	4050.2	4021.1	5008.6	5548.7	4726.3	4189.3	2825.3	1323.1	3961.6	4225.6
C80 (dB)	-6.03	-7.59	-7.59	-5.90	-4.03	-4.64	-2.60	2.26	-4.52	9.85
D50 (%)	8.49	18.22	11.15	15.14	21.74	19.16	28.03	52.30	21.78	43.81

TABLE IX
TRACK LIST OF AUDIO FILES CONTAINED IN THE 'AUDIO' FOLDER.

No.	Original Title	Source Material	IR Used	Format
1	0_Flute	Flute	None	Mono
2	0_Guitar	Guitar	None	Mono
3	0_Speech	Speech	None	Mono
4	0_Tambourine	Tambourine	None	Mono
5	1_IR_bform	None	1	B-format
6	1_IR_binrl	None	1	Binaural
7	1_Flute_bform	Flute	1	B-format
8	1_Flute_binrl	Flute	1	Binaural
9	1_Guitar_bform	Guitar	1	B-format
10	1_Guitar_binrl	Guitar	1	Binaural
11	1_Speech_bform	Speech	1	B-format
12	1_Speech_binrl	Speech	1	Binaural
13	1_Tambourine_bform	Tambourine	1	B-format
14	1_Tambourine_binrl	Tambourine	1	Binaural
15	2_IR_bform	None	2	B-format
16	2_IR_binrl	None	2	Binaural
17	2_Flute_bform	Flute	2	B-format
18	2_Flute_binrl	Flute	2	Binaural
19	2_Guitar_bform	Guitar	2	B-format
20	2_Guitar_binrl	Guitar	2	Binaural
21	2_Speech_bform	Speech	2	B-format
22	2_Speech_binrl	Speech	2	Binaural
23	2_Tambourine_bform	Tambourine	2	B-format
24	2_Tambourine_binrl	Tambourine	2	Binaural
25	3_IR_bform	None	3	B-format
26	3_IR_binrl	None	3	Binaural
27	3_Flute_bform	Flute	3	B-format
28	3_Flute_binrl	Flute	3	Binaural
29	3_Guitar_bform	Guitar	3	B-format
30	3_Guitar_binrl	Guitar	3	Binaural
31	3_Speech_bform	Speech	3	B-format
32	3_Speech_binrl	Speech	3	Binaural
33	3_Tambourine_bform	Tambourine	3	B-format
34	3_Tambourine_binrl	Tambourine	3	Binaural
35	4_IR_bform	None	4	B-format
36	4_IR_binrl	None	4	Binaural
37	4_Flute_bform	Flute	4	B-format
38	4_Flute_binrl	Flute	4	Binaural
39	4_Guitar_bform	Guitar	4	B-format
40	4_Guitar_binrl	Guitar	4	Binaural
41	4_Speech_bform	Speech	4	B-format
42	4_Speech_binrl	Speech	4	Binaural
43	4_Tambourine_bform	Tambourine	4	B-format
44	4_Tambourine_binrl	Tambourine	4	Binaural