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ACOUSTICALLY CHARACTERIZED 'EXPERIENCE OF TRANSCENDENCE' IN PFARKIRCHE ST MICHAEL, STEYR

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***Abstract**: 'Experience of Transcendence' is acoustically characterized in Pfarrkirche St Michael, Steyr using trained participants' feedback during live organ rendition of Johann Sebastian Bach's 'TOCCATA'. Transcendental experiences of 'awe', 'deeper understanding' and 'tranquility' were acoustically derived and termed as 'Acoustically Transcendent Awe' (AT_{AWE}), 'Acoustically Transcendent Intelligibility' (AT_{INT}), and 'Acoustically Transcendent Tranquility' (AT_{TRANQ}). In this study, 'Acoustically Transcendent Intelligibility' (AT_{INT}) and 'Acoustically Transcendent Tranquility' (AT_{TRANQ}) showed significant multiregressions with subjective acoustical qualities of the space (R^2=0.99; p=0.01) and (R^2=0.99; p=0.04) respectively. Instantaneous, statistical and percentile sound levels during ambient noise and during live performances were recorded at different listening zones. Background Noise Levels (LA_{90}) between 76dB-82dB indicated congregational and choir space as optimally loud (without any need for electro-acoustical support) and sanctuary (with LA90 value of 56.8dB) as needing support, for performance and listening. Acoustically Transcendent Intelligibility (AT_{INT}) was found significantly predictable from Subjective Acoustical Quality of Silence from Background Noise (SAQ_{SNOIS}) (p=0.05) and from Background Noise Level (L_{A90}) (p=0.05). Perception of optimal Reverberance (SAQ_{REV}) in the Choir Loft provides good ambience for choir and musicians. These significant relationships between Acoustical Transcendence Impressions, Subjective Acoustical Qualities and Sound Levels can serve as part of Pfarrkirche St Michael's unique intangible heritage.*

***Keywords:** Acoustical Transcendence Impressions, Subjective Acoustical Qualities, Instantaneous-statistical-percentile noise levels*

DOI:

1. INTRODUCTION

Pfarrkirche (Parish church) of St Michael in Steyr, shown in Fig. 1, was inaugurated in 1648. This church is popular amongst Austrian and international choirs for good acoustics. The main part of the interior of this church, shown in Fig. 2, characterized by late baroque and classicism, dates from 1763 to 1771. The organ comes from Garstner collegiate church and is a creation of Johann Ignaz Egedacher [1]. This organ was used by the likes of composer Anton Bruckner who was an organist at St Michael's [2].

Fig.1: Pffarrkirche St Michael, Steyr

Fig. 2: Pffarrkirche St Michael, Steyr. (A) High-Altar view; (B) Organ view

This study attempts to acoustically characterize ,experience of transcendence' in Pfarrkirche St Michael of Steyr. This exercise involves identifying significant relationships between perceived acoustical qualities and their capacity to induce a transcendental experience of; 'awe' 'deeper understanding' and 'stillness' for rendition of sacred music in a worship space. The derived prediction equations can work as 'character defining elements' of acoustically experiencing 'Transcendence' in that space.

This study builds on earlier research done in the acoustical characterization of worship ambience in churches [3-13].

2. METHODOLOGY

2.1. Measuring Instantaneous, Statistical and Percentile Sound Levels on a smart phone

Android based 'Noise Capture App' version 1.2.15 Jul3,2020r.32ec098 (developed for measuring environmental noise using a smartphone) [14] was used on Xiaomi Redmi Note 8 Pro (after calibration) to:

1. Measure instantaneous sound levels and Equivalent Noise Level (L_{eq}) in dB(A) on the whole measurement duration.
2. Measure a 'noise level spectrum' for each third octave band between 100Hz and 16KHz.
3. Measure statistical sound levels in dB(A): minimum, mean, maximum.
4. Analyse percentile noise levels in dB(A) over the whole measurement duration: Background Noise Level (L_{A90})-A-weighted noise level that is exceeded for 90% of the measurement period; Median Sound Level (L_{A50})-A-weighted noise level that is exceeded for 50% of the measurement period; Noise Annoyance Level (L_{A10})-A-weighted noise level that is exceeded for 10% of the measurement period;
5. Analyse Repartition of the Noise Exposure (RNE) representing the distribution of percentile sound levels over time of entire sound exposure.

2.2 Determining 'Acoustical Transcendence Impressions'

Twenty five listener recordings were obtained by moving five listeners to simultaneously record at five distinct listening zones: (A:mid-sanctuary); (B:frontal-nave); (C:mid-nave); (D:mid-narthex) and (E:Choirloft) as shown in Fig. 3.

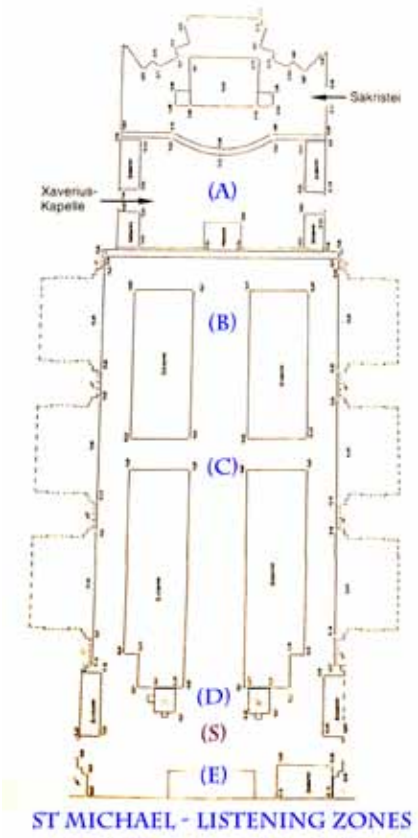

Fig. 3: Listening Zones (A-E) and Pipe organ location (S) in St Michael's church, Steyr

Pipe organist Astrid Mano rendered 'TOCCATA' of Johann Sebastian Bach from the Pipe Organ in the Choir Loft of the church (source location 'S'). Each rendition for each space was of 96 seconds duration. The listeners were instructed to score on the subjective acoustical qualities of the church using a structured questionnaire.

Each of these qualities provided a six point (0 to 5) differential scale on the evaluation sheet where ('0' implies '0% presence') ('1' implies 'very weak - 20% presence'); ('2' implies 'weak /mediocre - 40% presence'); ('3' implies 'fairly strong - 60% presence'); ('4' implies 'sufficiently strong - 80% presence'); ('5' implies 'optimally strong - 100% presence').

The following Subjective Acoustical Qualities were evaluated:

1. Subjective Acoustical Quality of Loudness (SAQ_{LOUD}) (The overall loudness or strength of the sound);
2. Subjective Acoustical Quality of Clarity (SAQ_{CLAR}) (The degree to which the musical notes are distinctly separated in time and clearly heard);
3. Subjective Acoustical Quality of Reverberance (SAQ_{REV}) (the persistence of sound);
4. Subjective Acoustical Quality of Directionality (SAQ_{DIR}) (the auditory impression that the sound comes from the axis of the sound source due to the arrival of substantial amount of direct sound);
5. Subjective Acoustical Quality of Intimacy (SAQ_{INT}) (the auditory impression of the apparent closeness of the source);
6. Subjective Acoustical Quality of Envelopment (SAQ_{ENV}) (the sense of being immersed in the sound or surrounded by it which happens when there is substantial amount of reverberant sound);
7. Subjective Acoustical Quality of Balance (SAQ_{BAL}) (the relative levels of bass and treble);
8. Subjective Acoustical Quality of Silence from Background Noise (SAQ_{SNOIS}) (where Background Noise is the sound heard other than from the source in the performance area);
9. Subjective Acoustical Quality of Silence from Echoes (SAQ_{SECHO}) (where Echoes are long delayed reflections that are clearly audible);
10. The Subjective Overall Acoustical Impression (SAQ_{OVER}) (the overall impression of the acoustical quality of the room).

The scored Subjective Acoustical Qualities were normalized into Acoustical Transcendence Impressions: Acoustically Transcendent Awe (AT_{AWE}), Acoustically Transcendent Intelligibility (AT_{INT}) and Acoustically Transcendent Tranquility (AT_{TRANQ}), using method used for deriving Acoustical Worship Impressions [15] Thus, Acoustical Transcendence Impressions are constituted using (1)

$$nATI = \frac{\sum(Y_{SAQ}X_{SAQ})_{MEAS}}{\sum(Y_{SAQ}X_{SAQ})_{REF}} \quad (1)$$

where,

nATI (as AT_{AWE}, AT_{INT} and AT_{TRANQ}) is a normalized value of the perceived impact of subjective acoustical qualities on the listeners perception of an 'Experience of Transcendence' ($-1 \le nATI \le +1$);

X_{SAQ} is the value of the subjective acoustical qualities ($0 \le X_{SAQ} \le +5$);

Y_{SAQ} measures perceived impact of acoustical qualities on Acoustical Transcendence Impressions (AT_{AWE}, AT_{INT} and AT_{TRANQ}) ($-1 \le Y_{SAQ} \le +1$);

$\Sigma(Y_{SAQ}X_{SAQ})_{MEAS}$ is a calculated value from X_{SAQ} and Y_{SAQ};

$\Sigma(Y_{SAQ}X_{SAQ})_{REF}$ is the optimal reference = 50.

This calculation also accomodates listeners' perception of being not sure of the expected 'acoustical transcendence experience' in a given space.

2.3 Musician's Criteria

The Musicians' criterion was assessed through an evaluation sheet filled through an interview with the performing pipe organist, Astrid Mano. Each question on the evaluation sheet provided a five point (-2 to +2) differential bipolar scale (where a score=0 implied the listener was 'not sure'). The questions posed to the performing musicians were:

1. Could you hear your own rendition clearly?
2. Did you enjoy playing your instrument in this church?
3. Did you feel content performing in this church?
4. How would you rate this church for performance?

The subjective data was analyzed using Microsoft Excel 2007 and Origin 6.1

2.4. Finding Significant Acoustical Relationships with transcendental experience

Significant regressions (at 95% level of significance) of Acoustical Transcendence Impressions (AT_{AWE}, AT_{INT} and AT_{TRANQ}) with Subjective Acoustical Qualities were identified as character defining elements of 'Acoustical Transcendence' in that space.

3. RESULTS AND DISCUSSION

3.1. Variance of Instantaneous, Statistical and Percentile Sound Levels in Different Listening zones.

The instantaneous, statistical and percentile sound levels for Ambient Noise and for live Performance on pipe organ at mid-sanctuary listening zone are shown in Fig. 4. Their counterparts at frontal-nave and mid-nave listening zones are shown in Fig. 5 and at mid-narthex and choir-loft listening zones are shown in Fig. 6.

The Ambient Noise in St Michael church was found to vary from a minimum of 46.5 dB to a maximum of 56.2 dB. Background Noise Level (L_{A90}) was at 46.7 dB, Median Sound Level (L_{A50}) was at 53.7 dB and Noise Annoyance Level (L_{A10}) was at 56.2 dB.

At mid-sanctuary listening zone, the noise levels varied from 48.5 dB to 95.7 dB. Background Noise Level (L_{A90}) was at 56.8 dB, Median Sound Level (L_{A50}) was at 87 dB and Noise Annoyance Level (L_{A10}) was at 92.2 dB.

At frontal-nave listening zone, the noise levels varied from 62.8 dB to 94.9 dB. Background Noise Level (L_{A90}) was at 77.5 dB, Median Sound Level (L_{A50}) was at 87.2 dB and Noise Annoyance Level (L_{A10}) was at 92.8 dB.

At mid-nave listening zone the noise levels varied from 50.6 dB to 94.9 dB. Background Noise Level (L_{A90}) was at 78.2 dB, Median Sound Level (L_{A50}) was at 87.5 dB and Noise Annoyance Level (L_{A10}) was at 92.5 dB.

At mid-narthex listening zone the noise levels varied from 54.6 dB to 95.9 dB. Background Noise Level (L_{A90}) was at 76 dB, Median Sound Level (L_{A50}) was at 88.3dB and Noise Annoyance Level (L_{A10}) was at 93.5 dB.

At choir-loft listening zone the noise levels varied from 54.4 dB to 97.9 dB. Background Noise Level (L_{A90}) was at 82 dB, Median Sound Level (L_{A50}) was at 90.4 dB and Noise Annoyance Level (L_{A10}) was at 96.4 dB.

Variance of L_{A90} in the nave, narthex and choir-loft between 76 dB and 82 dB indicates a sufficiently loud sound level for 90% of the listening period; L_{A90} value of 56.8 dB at mid-sanctuary listening zone is a weak level considering the variance of the ambient noise from 46.5 dB to 56.2 dB allowing no headroom at the higher end of the ambient noise.

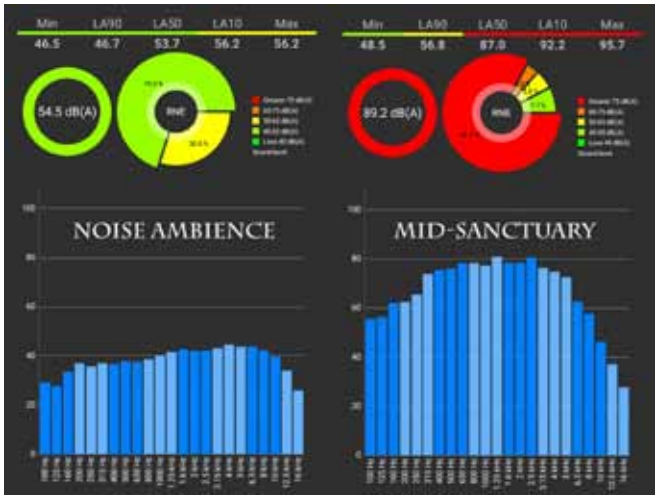

Fig. 4: Variance of Sound Levels at Ambient Noise and at mid-sanctuary listening zone during live performance

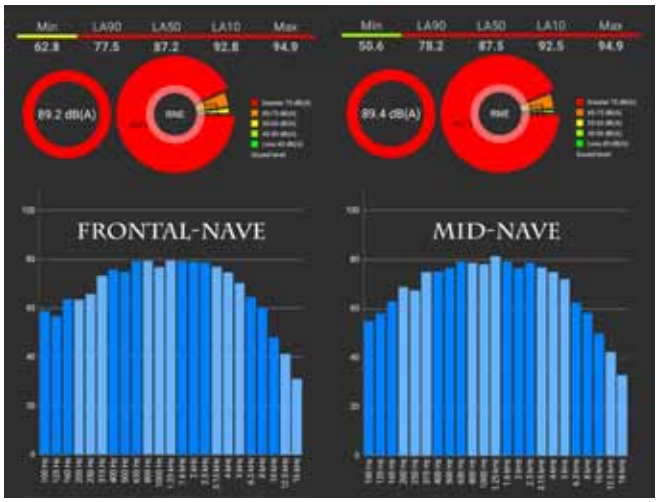

Fig. 5: Variance of Sound Levels at frontal-nave and mid-nave listening zones during live performance

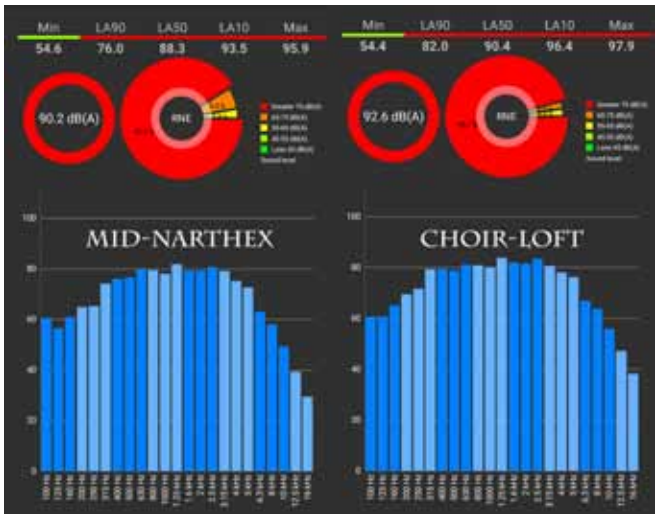

Fig. 6: Positional Variance of Sound Levels at mid-narthex and choir-loft listening zones during live performance

3.2. Listeners' Subjective Acoustical Perception and Musician's Criterion

The Subjective Acoustical Quality of Overall Impression of the Acoustics of the listening space (SAQ_{OVER}) was found to be significantly more perceptible than any individual subjective acoustical qualities (p=0.04) as shown in Tab. 1.

Data	Mean	p-value
SAQ_{LOUD}	4.24	0.04
SAQ_{CLAR}	3.96	
SAQ_{REV}	4.16	
SAQ_{DIR}	4.08	
SAQ_{INT}	3.92	
SAQ_{ENV}	4.0	
SAQ_{BAL}	4.12	
SAQ_{SNOIS}	3.6	
SAQ_{SECHO}	3.36	

Tab.1: ANOVA Tests on variance of different Subjective Acoustical Qualities

Organist Astrid Mano playing 'TOCCATA' of Johann Sebastian Bach on the church's pipe-organ expressed that all the musician's criteria were optimally obliged. She played and heard her rendition with good comfort, clear and loud. She expressed great satisfaction in performing in this church and rated her overall acoustical impression of the church at'5' on a scale of 1 - 5.

3.3. Significant Regressions between Measured and Derived Acoustical Parameters

'Acoustically Transcendent Intelligibility' (AT_{INT}) and 'Acoustically Transcendent Tranquility' (AT_{TRANQ}) showed significant relationship with. subjective acoustical qualities of Reverberance, Intimacy, Envelopment, Loudness, Clarity, Directionality, Balance, Noise and Echo (R^2=0.99; p=0.01) and (R2=0.99; p=0.04) respectively, as shown in Equations (2) & (3).

$$AT_{INT} = 0.15 - 0.035\,SAQ_{LOUD} + 0.12\,SAQ_{CLAR} - 0.08\,SAQ_{REV} + 0.02\,SAQ_{DIR} + +0.045\,SAQ_{INT} + 0.02\,SAQ_{ENV} - 0.05\,SAQ_{BAL} + 0.12\,SAQ_{SNOIS} - 0.07\,SAQ_{SECHO} \quad (2)$$

$$AT_{TRANQ} = -0.085 - 0.00003\,SAQ_{LOUD} + 0.14\,SAQ_{CLAR} - 0.03\,SAQ_{REV} + 0.03\,SAQ_{DIR} - 0.01\,SAQ_{INT} - 0.02\,SAQ_{ENV} - 0.08\,SAQ_{BAL} - 0.06\,SAQ_{SNOIS} + 0.07\,SAQ_{SECHO} \quad (3)$$

'Acoustically Transcendent Intelligibility' (AT_{INT}) showed significant positive correlation with subjective acoustical perceptions of Clarity (SAQ_{CLAR}), Directionality (SAQ_{DIR}), Intimacy (SAQ_{INT}), Envelopment (SAQ_{ENV}), and Silence from Background Noise (SAQ_{SNOIS}), and showed negative correlation with Loudness (SAQ_{LOUD}), Revereberance (SAQ_{REV}), Balance (SAQ_{BAL}) and Silence from Echoes (SAQ_{SECHO}) (R^2=0.99; p=0.01).

'Acoustically Transcendent Tranquility' (AT_{TRANQ}) significantly related positively with subjective acoustical qualities of Clarity (SAQ_{CLAR}), Directionality (SAQ_{DIR}) and Silence from Echoes ($SAQSECHO$) and related negatively with subjective acoustical qualities of Loudness (SAQ_{LOUD}), Revereberance (SAQ_{REV}), Intimacy (SAQ_{INT}), Envelopment (SAQ_{ENV}) and Silence from Noise (SAQ_{SNOIS}) (R^2=0.99; p=0.04).

'Acoustically Transcendent Intelligibility' (AT_{INT}) was found to significantly relate with Subjective Acoustical Quality of Silence from Background Noise (SAQ_{SNOIS}) (p=0.05), as shown in Equation (4)

$$AT_{INT} = 0.43 + 0.045\,SAQ_{SNOIS} \quad (4)$$

3.4. Significant impact of Background Noise Level (L_{A90}) on measured and derived acoustical parameters

'Acoustically Transcendent Intelligibility' (AT_{INT}) showed significant negative linear regression with L_{A90} (R=-0.87; p=0.056) as shown in Equation (5)

$$AT_{INT} = 0.956 - 0.00486\,LA90 \quad (5)$$

Subjective Acoustical Qualities of Envelopment (SAQ_{ENV}) and Silence from Echoes (SAQ_{SECHO}) showed significant negative linear regressions with LA90 (R=-0.91;p=0.03), (R=-0.89;p=0.04), respectively as shown in Equations (6) & (7)

$$SAQ_{ENV} = 7.59 - 0.048\,L90 \quad (6)$$

$$SAQ_{SECHO} = 5.33 - 0.026\,L90 \quad (7)$$

3.5. Variance of Acoustical parameters in different listening zones of the church.

Only the Subjective Acoustical Quality of Reverberance ($\boldsymbol{SAQ_{REV}}$) showed significant variance across different listening zones in which the participants recorded their feedback to live rendition of the organ. $\boldsymbol{SAQ_{REV}}$ was found to be significantly optimal in the Choir Loft ($\boldsymbol{p}$=0.02) as seen in Tab. 2.

Listener Zone	Mean	p-value
Sanctuary	5	0.02
Front Nave	4.4	
Mid Nave	3.2	
Narthex	3.6	
Choir Loft	4.6	

Tab. 2: ANOVA Tests on variance of ($\boldsymbol{SAQ_{REV}}$)

4. CONCLUSIONS

1. Background Noise Level ($\boldsymbol{L_{A90}}$) - a level exceeded for 90% of the listening period/exposure - stands out as important acoustical parameter to judge the need of electro-acoustical interventions for a given listening space. Therefore, an optimally loud Background Noise Level ($\boldsymbol{L_{A90}}$) between 76 dB and 82 dB in the nave, narthex and choir-loft makes the congregational and choir seating and performing space ideal for proclamation, singing, music and listening without any electro-acoustical aid. The sanctuary with its Background Noise Level ($\boldsymbol{L_{A90}}$) at 56.8 dB needs electro-acoustical support for the presiding priests and lectors to be able to comfortably communicate and celebrate the liturgy.
2. The listeners' perception of Subjective Acoustical Quality of overall impression of the acoustics of this church ($\boldsymbol{SAQ_{OVER}}$) being found better than their perception of any individual Subjective Acoustical Quality that was scored upon, and the organist giving maximum scores on all Musician's criteria for a performing space, indicates presence of optimal acoustical comfort for performing and listening in this church.
3. Acoustically Transcendent Intelligibility ($\boldsymbol{AT_{INT}}$) and Acoustically Transcendent Tranquility ($\boldsymbol{AT_{TRANQ}}$) can be significantly predicted in this church from a multiregression on perceived Subjective Acoustical Qualities of Loudness, Clarity, Revereberance, Directionality, Intimacy, Envelopment, Balance, Silence from Noise, Silence from Echoes and overall impression of acoustics of the space.
4. Acoustically Transcendent Intelligibility ($\boldsymbol{AT_{INT}}$) can be significantly predicted in this church through a positive linear regresion on Subjective Acoustical Quality of Silence from Background Noise ($\boldsymbol{SAQ_{SNOIS}}$).
5. Acoustically Transcendent Intelligibility ($\boldsymbol{AT_{INT}}$) can be significantly predicted in this church through a negative linear regresion on Background Noise Level ($\boldsymbol{L_{A90}}$).
6. Subjective Acoustical Qualities of Envelopment ($\boldsymbol{SAQ_{ENV}}$). and Silence from Echoes ($\boldsymbol{SAQ_{SECHO}}$). can be significantly predicted in this church through a negative linear regresion on Background Noise Level ($\boldsymbol{L_{A90}}$).
7. Amongst all measured and derived acoustical parameters, only Subjective Acoustical Quality of Reverberance ($\boldsymbol{SAQ_{REV}}$) showed significant variance across different listening zones of the church. $\boldsymbol{SAQ_{REV}}$ was found to be better perceived in the Choir Loft. The perception of optimal reverberance creates good ambience (working like natural monitors) for the performing choir and musicians in the choir loft.
8. Optimal Sound Levels during performance (as indicated by $\boldsymbol{L_{A90}}$), Optimal Acoustical Comfort (as indicated by better perception of $\boldsymbol{SAQ_{OVER}}$ coupled with optimal musicians' contentment), Optimal Reverberance in the Choir Loft (as indicated by scores of $\boldsymbol{SAQ_{REV}}$) justify the popular good rating for this church amongst church goers and choirs.
9. Amongst the three derived Acoustical Transcendent Impressions, 'Acoustically Transcendent Intelligibility ($\boldsymbol{AT_{INT}}$) was found to be more significantly predictable from perceived Subjective Acoustical Qualities and Background Noise Level ($\boldsymbol{L_{A90}}$).
10. Trained Listeners' perception of subjective acoustical qualities of a space as evoking experience of 'Transcendence' in the form of 'Awe', 'Deeper Understanding or Intelligibility' and 'Stillness inducing Tranquility' creates a credible soundscape that captures the capacity of the worship space of Pfarrkirche St Michael, Steyr to induce a unique 'Experience of Acoustical Transcendence'.

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