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Evaluation of Acoustic Silence, Acoustic Intelligibility and Acoustic Sacred Factor in Goan Catholic Churches

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ABSTRACT

Acoustic Silence, Acoustic Intelligibility and Acoustic Sacred Factor are the acoustically constituted determinants of tranquillity in a Catholic church. The results presented here are part of a study that investigates the behaviour of derived acoustic parameters in worship spaces. Acoustically, *Silence Factor* (SiF) is found to decay quadratically with L_{Aeq} (R^2=0.95, p<0.01); *Intelligibility Factor (InF)* decays quadratically with mid-frequency Loudness G_{MF} (R^2=0.69, p<0.01) and the prediction of *Sacred Factor* is found to be insignificant. Architecturally, *Silence Factor is found to grow* linearly with the width of the nave (of the church) (R^2=0.69, p=0.04), *Intelligibility Factor* grows linearly with the minimum height of the nave (H_{MIN_NV}) (of the church) (R^2=0.91, p<0.01) and the regression of *Sacred Factor* is found to be insignificant with the dimensional parameters. The prediction equations presented here could enable a more scientific approach to design and conservation of worship space.

Keywords: Acoustics, Tranquillity, Church

1. INTRODUCTION

Acoustics plays active role in ensuring an experience of tranquillity in a worship space. Acoustic factors such as speech, music, singing and silence need to be blendfully optimized [1][2] in order to enable Christians optimally experience being the mystical Body of Christ during community worship [3].The results presented here are part of a research program that explores the aesthetics of worship through acoustically constituted categories [4-6]. Among the Acoustic Worship Indices (AWI), *Silence Factor* (SiF) is a derived acoustic parameter that characterizes the worship aesthetic of silence. *Intelligibility Factor* (InF) acoustically comprehends the intelligibility in sacred music and speech. *Sacred Factor* (SaF) evaluates reverential awe in a worship space. The results reported here, are based on field measurements done in the following six Catholic churches of Goa, India: Capela do Monte church (CH1), Bom Jesus Basilica (CH2),our Lady of Pilar church (CH3), our Lady of Divine Providence church (CH4), Holy Spirit church (CH5) and Holy Trinity church (CH6). The first five churches (CH1 – CH5) were built in the 16th and 17th centuries, during the Portuguese era in Goa and are European derivatives subtly influenced by the Indian worship aesthetics. The sixth church (CH6) is a contemporary style church. The observed relationship of SiF, InF and SaF with measured acoustical

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parameters and with dimensional parameters indicates the acoustical and architectural measures that can optimize tranquillity in a church. The purpose of this work is to explore as to whether the Worship Ambience can be significantly quantified through evaluation of *SaF*, *InF* and *SiF* and also to find out as to which of the acoustically derived worship indices can be significantly predicted through evaluation of acoustical and dimensional parameters.

2. EXPERIMENTAL PRELIMINARIES

2.1 Dimensional Parameters

The architectural parameters measured or evaluated in the sample churches are: Total sound absorption (ABS_{TOT}); Average coefficient of absorption (C_{ABS}); Total surface area of church (A_{TOT}); Total surface area of church nave (A_{NV}); Maximum height of the church (H_{MAX}); Maximum height of church nave (H_{NV}); Maximum length of the church (L_{MAX}); Maximum length of church nave (L_{NV}); Volume of church (V_{TOT}); Volume of nave (V_{NV}); Average height (H_{AVG}); Maximum nave width (W_{NV}); Average width (W_{AVG}); Minimum nave width (W_{MIN_NV}); Average nave width (W_{AVG_NV}); Minimum nave height (H_{MIN_NV}); Average nave height (H_{AVG_NV}); Nave proportions (L_{NV} / H_{NV}) and (W_{NV} / H_{NV}). The simple statistics of the architectural details of the sample churches are shown in Table 1.

Table 1 – Simple statistics of dimensional parameters of the sample churches

	MIN	MEAN	MAX	MED	SD	SKEW	KURT	CONF
ABS_{TOT}	47	199	387	163	143	0.49	-1.93	115
C_{ABS}	0.03	0.048	0.07	0.04	0.02	0.73	-1.73	0.01
A_{TOT}	250	755	1168	805	369	-0.36	-1.56	295
A_{NV}	81	329	630	296	238	0.20	-2.60	191
H_{MAX}	15	21.17	30	21.5	5.71	0.39	-0.28	4.57
H_{NV}	9	18.67	30	18	7.28	0.39	0.15	5.83
L_{MAX}	30	41.83	61	34.5	15.01	0.88	-1.89	12.01
L_{NV}	14	22.17	36	18	9.77	0.86	-1.64	7.81
V_{TOT}	2974	9382	18858	6726	7052	0.75	-1.83	5642
V_{NV}	837	5657	13613	3556	5244	0.88	-1.17	4196
H_{AVG}	8	11.67	16	10.5	3.61	0.48	-2.20	2.89
W_{NV}	9	13.67	23	11.5	5.85	0.88	-0.67	4.68
W_{AVG}	7	13	17	15	4.38	-0.79	-1.81	3.51
W_{MIN_NAVE}	9.2	11.77	18	10.1	3.58	1.32	0.82	2.87
W_{AVG_NAVE}	8.85	12.71	18	11.6	4.19	0.35	-2.48	3.35
H_{MIN_NAVE}	9	13.1	16.5	14.05	2.97	-0.56	-1.49	2.37
H_{AVG_NAVE}	12.3	16.9	21.75	17.1	3.32	0.04	-0.23	2.65
L_{NV}/H_{NV}	0.81	1.28	1.92	1.11	0.47	0.73	-1.71	0.38
W_{NV}/H_{NV}	0.39	0.815	1.42	0.745	0.35	0.99	1.62	0.28

SD - standard deviation, SKEW - Skewness, KURT - kurtosis, CONF - 95% confidence intervals.

The large values of the standard deviation (SD) of the Volume of the churches (V_{TOT}) and of the Volume of the naves of the churches (V_{NV}) indicate the large variance in the volume of the churches chosen which justifies them as sufficiently representative of different architectural genres of churches available in Goa.

2.2 Subjective Acoustic Impressions

The acoustic evaluation sheet [7, 8] given to the listeners was interpreted to accommodate parameters of worship [4, 5]. Accordingly, the experience of reverential awe, the quality of intelligibility and the quality of silence were expressed as averages of Subjective Acoustic Impressions (SAI). The subjective data was analyzed using *Excel* and *Origin 6.1*.

2.3 Objective Acoustical Measurements

The objective acoustic parameters [Noise Ambience (L_{eq}), Reverberation Time (RT), Loudness (G), Rapid Speech Transmission Index (RASTI) and Energy Time Graph (ETG)] were directly measured in unoccupied churches using the '*Terrasonde Audio Tool Box 2.0*' [henceforth coded as 'ATB'] and '*Terralink*'. A detailed Energy-Time Graph [ETG] analysis in compliance with the ISO-3382 standard [9], generated the following important objective monaural acoustic parameters: Definition [D_{50}], Clarity [C_{80}], Initial Time Delay Gap [ITDG], Centre time [TS] and Early Decay time [EDT].

2.4 Derived Acoustical Parameters

Various subjective and objective acoustical parameters were normalized such that the normalized parameters are equal weighted constituents of the derived Acoustic Worship Indices (AWI): Sacred Factor (SaF), Intelligibility Factor (InF) and Silence Factor (SiF). Accordingly, SaF as an acoustic worship parameter is a description of the evolution from *Awe* to *Reverence* and *Metanoia.* InF measures the quality of the communion between the 'Word' and the 'Listener'. It also measures the intelligibility of the communication between the 'human' and the 'divine'. SiF covers the extensive journey from *solitude* to *serenity* to *surrender* that a worship space animates one into [10 – 12].

3. RESULTS

3.1 Inter-church variation of SaF, InF and SiF

The inter-church variation of SaF, InF and SiF in comparison with Acoustic Comfort Impression Index (ACII) [4, 5] is shown in Figure 1.

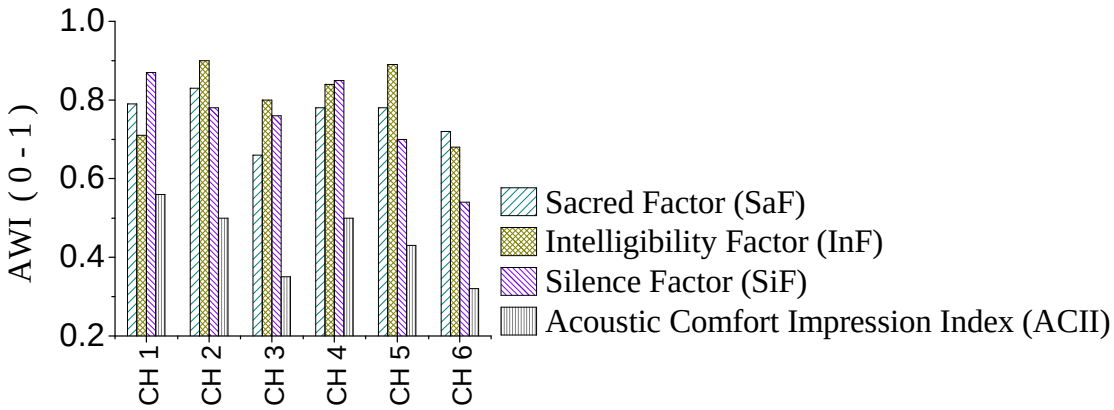

Figure 1: The inter-church variation of the Acoustic Worship Indices (AWI)

The inter-church variance of the SaF, InF, SiF and ACII reflects the impact of the architectural styles on these derived acoustic parameters. Among the derived parameters in each church, SaF shows priority in Holy Trinity church (CH6) while InF prevails in Bom Jesus Basilica (CH2), Our Lady of Pilar church (CH3) and Holy Spirit church (CH5). The SiF is prominent in Capela do Monte (CH1) and Our Lady of Divine Providence church (CH4). Among the churches, Bom Jesus Basilica (CH2) recorded the better score of SaF; Bom Jesus Basilica (CH2) and Holy Spirit church (CH 5) are better than other churches in their InF score. The best scores for SiF and ACII are seen in Capela do Monte (CH1).

3.2 Best Prediction Equations and Best Fits

The best prediction equations (based on acoustical parameters) for the AWI and the acoustic measures as constructed from the regression on all the averaged data points in all the sample churches are shown in Table 2.

Table 2: Best prediction equations (for averaged 4 points/church data points in 6 churches = 24 points)

NO	EQUATION	R^2	SD	p - value
1	SaF = 0.88 - 0.004 ITDG	0.38	0.07	< 0.01
2	InF = 0.73 + 0.04 G_{MF} - 0.003 G_{MF}^2	0.67	0.06	< 0.01
3	SiF = 0.92 + 0.01 L_{Aeq} - 0.0003 L_{Aeq}^2	0.95	0.03	< 0.01

(G_{MF} - Loudness mid frequency)

The corresponding best fits are elucidated in Figure 2.

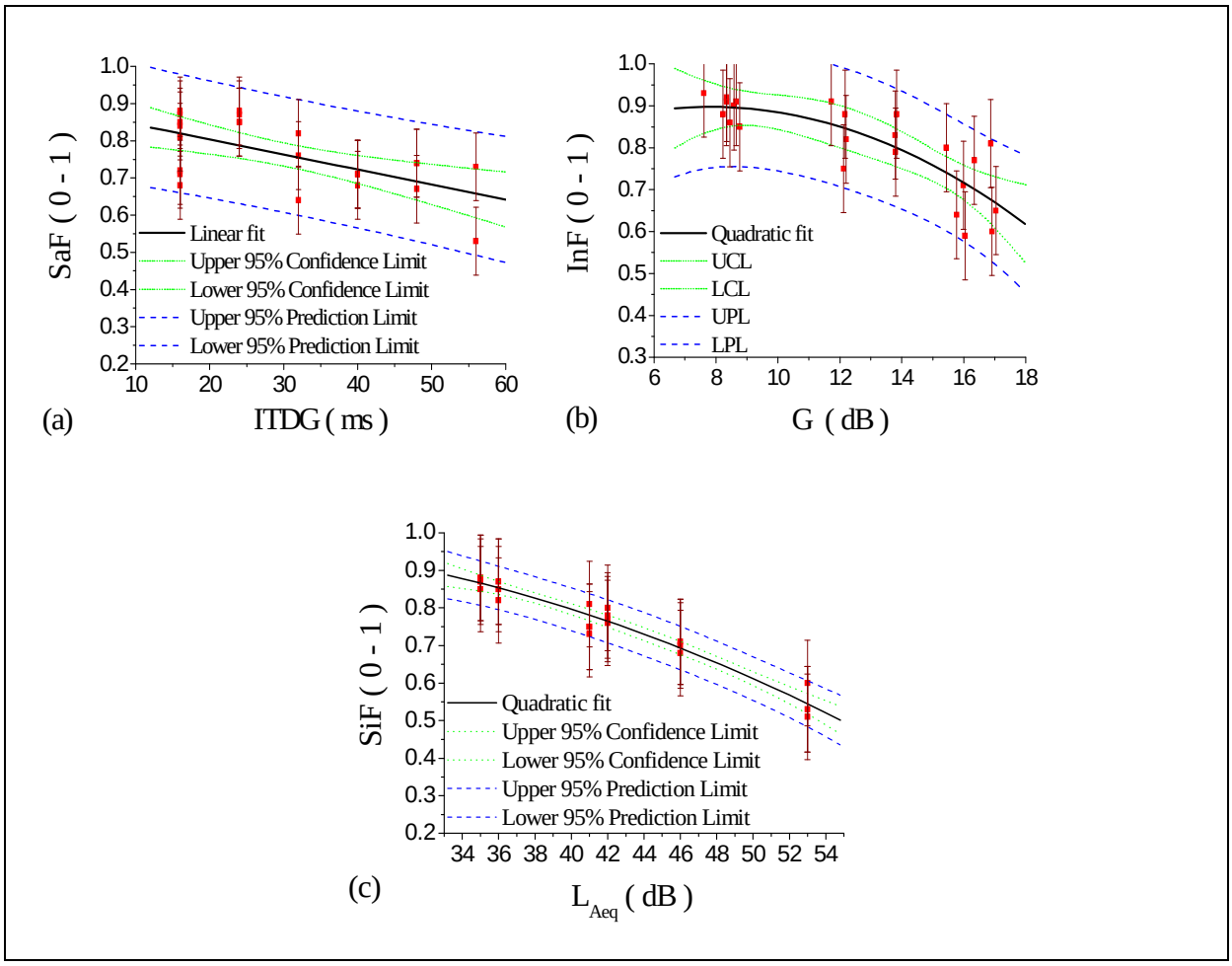

Figure 2: Best fits for the general averages of Acoustic Worship Indices (AWI): (a) Linear fit of SaF on ITDG, (b) Quadratic fit of InF on G, (c) Quadratic fit of SiF on L_{Aeq}, (d) Linear fit of SiF on ACII, (E) Exponential Growth fit of SiF on ACI [S].

The best prediction equations (based on the architectural dimensions) for the averaged values of AWI along with their respective coefficients of determination, values of standard deviation and the probability values in the church are shown in Table 3.

Table 3: Best Prediction Equations for measured and derived acoustic parameters based on architectural details

NO	EQUATION	R^2	SD	p - value
1	SaF = 0.62 + 0.01 H_{AVG}	0.49	0.05	0.12
2	InF = 0.42 + 0.03 H_{MIN_NV}	0.91	0.03	< 0.01
3	SiF = 0.98 - 0.02 W_{NV}	0.69	0.07	0.04

A confidence greater than 99% (p = 0.01) was generalized and denoted as 'p < 0.01'.

The best fits of Acoustic Worship Indices (SaF, InF and SiF) on the most significantly relating architectural measures are shown in Figure 3.

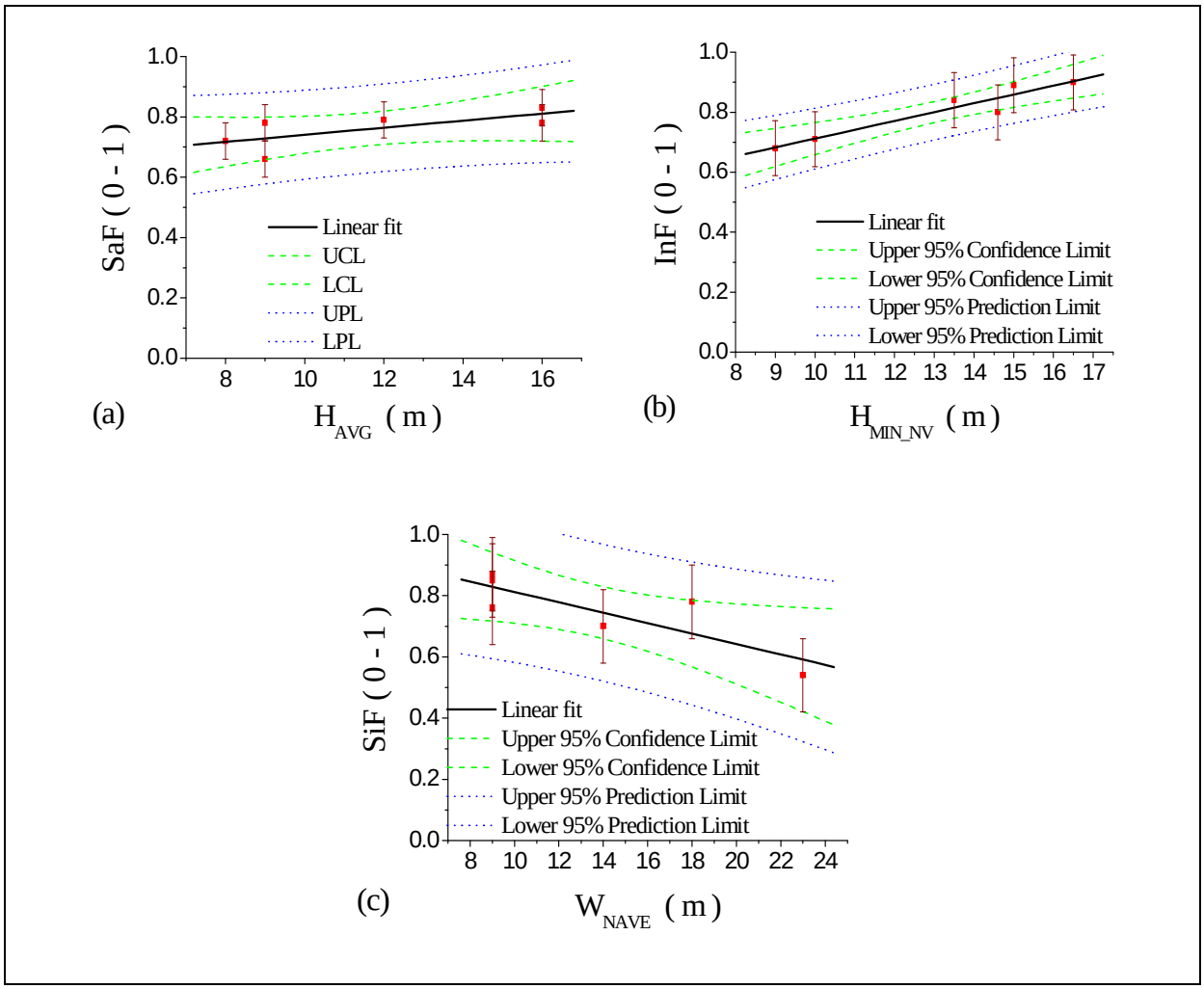

Figure 3: Best fits of AWI based on architectural measures: (a) Linear fit of SaF on H_{AVG}, (b) Linear fit of InF on H_{MIN_NV}, (c) Linear fit of InF on $W_{NV.}$

4. CONCLUSIONS

The prediction equations and the best fits indicate the plausibility of significantly predicting *AWI* based on acoustical and architectural parameters. The following inferences could be confidently drawn from the results listed above:

a) *Amongst the AWI*, although *InF* with a mean value of 0.80 is greater than the averages of the other *AWI*, *SiF* is the most significantly predictable index based on acoustical parameters, as seen from the final regression analysis data and the best prediction equations for AWI (for averaged four

points/church data points in six churches = 24 points) wherein: Quadratic regression of SiF by L_{Aeq} is based on R^2=0.95, SD=0.03, p<0.01; Quadratic regression of InF by G is based on R^2=0.67, SD=0.06, p<0.01; Linear regression of SaF by ITDG is based on R^2=0.38 SD=0.07, p<0.01 and therefore not very significant.

b) Each of the three AWI was predicted by a distinct architectural parameter: SaF linearly predicted by the average height of the church (H_{AVG}); InF linearly predicted by the minimum height of the nave (H_{MIN_NV}) and SiF linearly predicted by the maximum width of the nave (W_{NV}). However, the *p value* indicates that the prediction of SaF by dimensional parameters is not very significant.

c) As compared to acoustic intelligibility and acoustic silence, acoustic sacred factor was found not to be significantly predicted either by acoustical or dimensional parameters thus the description of reverential awe remains (for the time being) in the subjective domain.

The results describe the plausibility of the dynamics of experiencing the Divine in a House of Worship being acoustically comprehended, characterized, evaluated, predicted and designed. This acoustic wisdom will usher a heightened transformation in understanding worship acoustics and make the design of a worship space a graceful art.

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