ABSTRACT
The 'Tranquility' factor in Christian worship can be acoustically expressed as an optimized blend of silence, awe and intelligibility. These derived acoustic parameters in this study are called 'Acoustic Comfort Impression Index [ACII]' and Subjective Speech Intelligibility Index [SSII] with respect to live music and speech respectively. This study presents the behaviour and optimized prediction of ACII and SSII, by subjective and objective acoustic measures, in two catholic churches of Goa coded as HSCH and HTCH respectively. ACII for different signal sources and music types and SSII for different signal sources and languages were analyzed and averaged in 4 listener zones using Excel and Origin 6.0. Terrasonde Audio Tool Box 2.0 along with Terralink and AutoCAD was used for measuring objective acoustic parameters (RASTI, RT60, D50, C80, TS, LEF, ITDG, EDT, G, etc.) at different locations in each church. ACII_HSCH was found higher than ACII_HTCH and best predicted by subjective clarity and objective Loudness Index while ACII_HTCH was best described by subjective reverberance and objective TS. SSII_HSCH and SSII_HTCH nearly tallied and both suitably predicted by D50, C80 and RASTI. These results incorporated in the early stages of design can therefore decisively create tranquility in a church.

INTRODUCTION
Practical directives, based on a relationship between liturgical principles, acoustic measures and architectural features are essential for ecclesiastical architecture [1] [2] [3] [4]. In this study, derived acoustic parameters, named as 'Acoustic Comfort Impression Index [ACII]' and 'Subjective Speech Intelligibility Index [SSII]' are used to express the 'tranquility factor' in Christian worship as an optimized blend of silence, awe and intelligibility. The main hypothesis is that ACII and SSII are measurable and predictable.

METHODOLOGY
The Sample Churches
The acoustical findings in this paper are based on field measurements carried out in the Holy Spirit Church [1661-1668] [Indian Baroque Quintet]
and the Holy Trinity Church[2005][contemporary design] which are coded as ‘HSCH’ and ‘HTCH’ respectively.

Listeners and Music-Speech Sources
Nineteen trained normal listeners were spatially seated into four seating zones within the church. The contemporary choir location and the balcony choir location of the church were chosen as Music Source positions ‘SA’ and ‘SB’ respectively. The altar, pulpit and the high altar locations were chosen as Speech Source positions ‘SA’ and ‘SB’ and ‘SC’ respectively. The speakers (a Catholic Priest and a Lady Theatre Art Professional) alternately read out selected 50 words in Konkani and English languages from the prepared Modified Rhyme test [MRT] word lists. The Cellist played “Bach’s Suite No. 2”. The Clarinet player and the two violinists played “Motet: Fera Pessima” a traditional Christian Lenten hymn, for the solo and the duet respectively. The ensemble played a Goan devotional classic “Piedade Saibinni in minor and major”.

Subjective Evaluation Method and Terminology
A wholistic tranquillity feeling in the celebration of corporate worship in a church is an inspiring synergy of awe, silence and intelligibility. The acoustic evaluation sheet [5] given to the listeners was interpreted to accommodate these three parameters of worship. The experience of reverential awe was expressed as four desirable Subjective Acoustic Impressions (SAI): intimacy (SAI_INTI), envelopment (SAI_Env), reverberance (SAI_REV) and overall impression (SAI_OVER). The quality of Intelligibility of speech, singing and music was judged from another four desirable Subjective Acoustic Impressions (SAI): Loudness (SAI_Loud), Clarity (SAI_CLAR), directionality (SAI_DIR) and clarity (SAI_BAL). The quality of silence was judged from two undesirable Subjective Acoustic Impressions (SAI): background noise (SAI_NOIS) and echoes (SAI_ECH). Desired and Undesired Subjective Acoustic Impressions (DSAI and USAI) refer to the averages of the desired eight SAI and the undesired two SAI respectively. The difference between DSAI and USAI is averaged and coded as the Acoustic Comfort Impression Index (ACII). The Subjective Speech Intelligibility Index (SSII) is the averaged and indexed value of the %words understood by the listener. The subjective data was studied using Excel and Origin 6.1.

Measurement of Objective Acoustic Parameters
The objective acoustic parameters [Noise Ambience, RT60, RT40, RASTI, Sound Energy Decay curve] 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 with the aid of AUTOCAD software based ‘Mirror Image Source Method’ [MISM], in compliance with the ISO-3382 standard [4,5,6,7], generated the following important objective acoustic parameters: Definition [D50], Clarity [C80], Center time [TS], Sound Pressure level [SPL], Early Lateral Energy Fraction [EARLY LEF], late Lateral Energy Fraction [LATE LEF], Early Support [STE], Late Support [STL], Total Support [STT], Intimacy [I], Early Decay time [EDT], Reverberation time [RT60cal], Liveness [Live], Loudness Strength Factor [G] and Loudness Index [LI].

RESULTS AND DISCUSSION
Significant differences were noticeable in the various acoustic parameters for the churches analyzed. To pick a few, considerable variance in ACI, SSI, RT60 and RASTI in the churches is shown in Figure I. The uniqueness in the behaviour of ACII and SSII in the churches can be assessed from a close
inspection of the optimized prediction equations along with the correlation coefficients and the coefficients of determination for these and the important correlating individual acoustic measures (Table 1). The optimized fits for ACII and SSSI are shown in Figure 2.

In HSCH the ACII shows excellent correlation with SAI_CLAR and is objectively best predicted by the Loudness Index ‘LI’. C80 is best-fitted with SAI_CLAR so as to make it a suitable objective counterpart. However the latter has better correlation with the objective parameters Intimacy ‘I’[R=0.7] and Loudness Index ‘LI’[R=0.95]. RASTI is found to be a highly suitable objective counterpart for SSI in HSCH and yet the best relationship of SSI [R=0.99] is with D50 and C80 expressed as a multiple regression with a coefficient of determination [R^2=0.99]. In HTCH, the ACII is predicted by the negatively correlating parameters, SAI_REV and TS respectively. The negatively correlating parameter, RT40, is found to be a highly suitable objective counterpart to predict SAI_REV in HTCH. The SSI in HTCH can be predicted by a number of highly correlating objective parameters such as RASTI[R=1], D50[R=1], C80[R=0.96] and STE[R=-0.9]. We have presented, only its best fit with EARLY LEF and its multiple regression with D50 and RASTI which are its closest intelligibility objective counterparts. The capacity of ACI and SSI to comprehend and predict the worship tranquility factor in a church will be further explored. The correlation of the sound energy with its lateral distribution, within intelligibility limits and within moments of silence in worship, will provide the ACI indices for a varied impact of music on the worship tranquility factor in the different churches.

Figure 1. Variance in ACI, SSI, RT60 and RASTI in the churches.
Table 1: OPTIMIZED PREDICTION EQUATIONS FOR ACII AND SSII

| CHURCHES AND EQUATIONS | ACI_HSCH = 117.89 - 611.7\(L_{\text{INDEX}}\) + 1049.4\(L_{\text{INDEX}}^2\) - 592.2\(L_{\text{INDEX}}^3\) | 0.9 | 1.00 |
| | ACI_HSCH = 23979 - 12138 SAI_CLAR + 2048 SAI_CLAR^2 - 115 SAI_CLAR^3 | 0.99 | 1.00 |
| | SAI_CLAR = 5.54 - 11.34 C80 - 81.98 C80^2 + 166.11 C80^3 | 0.65 | 1.00 |
| | SAI_CLAR = 5.44 + 0.02 I + 0.79 LI | 0.91 |
| | SSI_HSCH = -1.802 + 14.06 RASTI_CH - 24.36 RASTI_CH^2 + 13.87 RASTI_CH^3 | 0.92 | 1.00 |
| | SSI_HSCH = 0.33 + 0.44\(\exp\{0.92(\text{RASTI}_\text{CH} - 0.87)\}\) | 0.92 | 0.99 |
| | SSI_HSCH = 0.65 + 0.32D50 + 0.76C80 | 0.99 |
| HTCH, BENAULIM | ACI_HTCH = -196.03 +101.62 SAI_REV -17.48 SAI_REV^2 + SAI_REV^3 | -0.87 | 1.00 |
| | ACI_HTCH = 0.3 + 0.07\(\exp\{0.912(\text{SAI}_\text{REV} - 5.56)\}\) | -0.87 | 1.00 |
| | SAI_REV = -5945.7 + 2160.81\[\text{RT40}\] -195.51\[\text{RT40}\]^2 | -0.98 | 1.00 |
| | ACI_HTCH = -24476.24 +590 TS - 4.74 TS^2 + 0.01TS^3 | -0.68 | 1.00 |
| | SSI_HTCH = 0.84+0.13\(\exp\{-559.41(\text{LEF} - 0.96)\}\) | 0.96 | 1.00 |
| | SSI_HTCH = 2.08 -1.37D50 +1.1RASTI_CH | 0.8 |

Figure 2: Best fits for the most significant relationships in both the churches

CONCLUSIONS
The results presented in this paper indicate that significant and unique relationships exist between the subjective acoustic criteria for worship and
the objective acoustic parameters measured in these two churches belonging to two different era. The optimized predictions equations for ACII, SSII and the individual most significant SAI indices in terms of objective acoustic parameters indicate the plausibility of acoustically measuring and predicting the worship tranquility factor in proportions of Awe, Silence and Intelligibility.

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