

# PRE-RESTORATION CHARACTERIZATION OF ACOUSTICAL HERITAGE OF NOSSA SENHORA DO PILAR CHURCH, GOA

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## Abstract

The church of Nossa Senhora do Pilar built in 1613 by the Spanish Franciscan Capuchos is part of the Convento do Pilar, Goa. This diminished sanctuary church with Rococon Mannerist features underwent repairs wherein the original lime mortar mix on its laterite stone walls was replaced by cement plaster - paint coat and ceramic tiles. Besides triggering a salt attack, the replacement of original lime mortar caused a change in the surface sound absorption values inside the church. The acoustical properties inside the church too suffered change. The restoration of this 400 year old church has begun. A method of capturing the acoustical sacred heritage of the church using objective acoustical parameters (*RASTI*, *RT*, *D50*, *C80*, *TS*, *ITDG*, *G*, and *LAeq*) and subjective acoustic impressions is presented in this study. The values obtained in this pre-restoration survey will be compared with those obtained through a similar acoustical characterization of the worship ambience inside the church after the inner surface of the walls is replastered with the original lime-mortar overcoat. This will enable a comparative explanation of the restoration of *the acoustical heritage* of Nossa Senhora do Pilar church.

## 1. INTRODUCTION

The desire for religious comfort and solace brings a devotee to a worship space. The subjective comfort inside any sacred heritage environment depends not only on visual perception but a combined data originating from all the five senses. This study presents a preliminary (Phase I) acoustical survey involved in the restoration of a 400 year old, Nossa

Senhora do Pilar church in Pilar, Goa. The hybrid architectural sacred heritage which is to be conserved/restored includes visual (structural/architectural/art) heritage and acoustical heritage components. What is visually perceived and acoustically heard and felt shapes the subjective experience of the Divine in a worship space. A good acoustical ambience facilitates the experience of subjective comfort in a worship space thus enabling *Active, Conscious and Total Participation* of the devotee in community worship [1] and as such constitutes the acoustical sacred heritage of a church.

**2. ARCHITECTURAL HERITAGE OF THE CHURCH**

Nossa Senhora do Pilar church is in the Mannerist Neo-Roman style with prominent influences of the Indian Aesthetic [2][3] as shown in Figure 1.

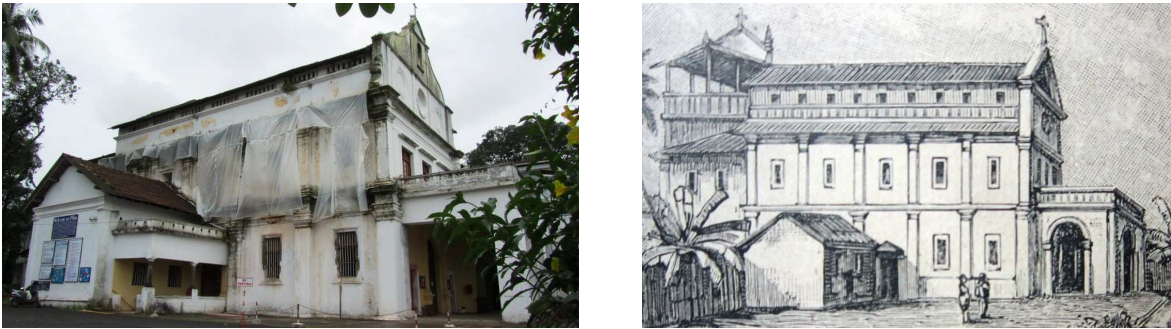


Figure 1: Nossa Senhora do Pilar church (left: present state; right: old painting [4])

Some important architectural details of Nossa Senhora do Pilar church are shown in Table 1.

Table 1: Architectural details

ARCHITECTURAL MEASURES	DESCRIPTION	UNITS	VALUES
Total Floor Area	$A_{TOT}$	$m^2$	400
Nave Floor Area	$A_{NV}$	$m^2$	130
Maximum Height	$H_{MAX}$	m	15
Maximum Length	$L_{MAX}$	m	30
Total Volume	$V_{TOT}$	$m^3$	3457
Nave Volume	$V_{NV}$	$m^3$	837
Total Average Height	$H_{AVG}$	m	9
Maximum Nave Width	$W_{NV}$	m	9
Average Width	$W_{AVG}$	m	8

The plan of the church is of a diminuted sanctuary style, with a larger nave leading to a smaller sanctuary as shown in the floor plan and sections in Figure 2 and Figure 3 respectively.

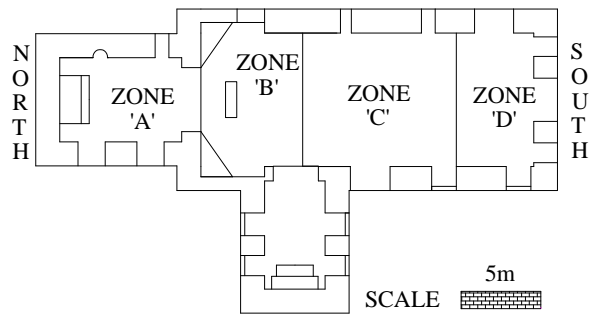


Figure 2: Ground floor plan of Nossa Senhora do Pilar church. (Floor plan courtesy: Engr. Thomas D’Costa).

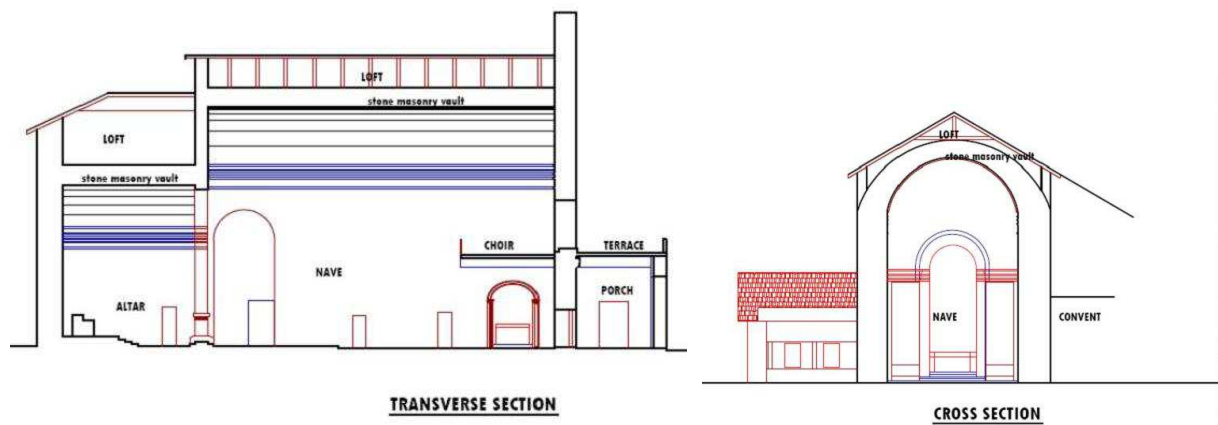


Figure 3: Sections of Nossa Senhora do Pilar church. (scaled to fit)

The nave roof consists of a barrel vault in laterite stone masonry whose soffit is plain, devoid of any reticulation. The sanctuary is roofed by a smaller barrel vault with a coffered soffit. A comparison of the interior of the church before and after some portion of the inner walls was deplastered is shown in Figure 4.



Figure 4: Comparison of the interior of the church before and during restoration.

### 3. IMPROPER INTERVENTIONS & MODIFICATIONS

#### 3.1 Internal Visual and Acoustical Damage

The surface materials in Nossa Senhora do Pilar church interior did not appear harmonious as a result of non-scientific interventions and modifications over the years. The Art Deco style [5] decorations are superimposed over the Neo-Roman style of the church. The original basalt stone or wooden floor of the nave and sanctuary has been redone in insitu marble mosaic flooring. The altar was placed on a wooden platform with a red carpet. The side altars have gold paint but have been retouched with green oil paint and other such finishes. The choir loft has been reconstructed in reinforced concrete, with its beam soffits visible, whereas the original choir loft would have been in timber or of a stone masonry vault. The original lime mortar mix on its laterite stone walls was replaced by cement plaster - paint coat and glazed ceramic tiles. The change of surface materials on the inner surface of walls and floor and the replacement of the wooden choir loft by a reinforced concrete messanine floor has caused a change in the surface sound absorption values inside the church. The acoustical properties inside the church too suffered change. This conflict of materials is shown in Figure 5.

#### 3.2 Structural Damage

The mangalore-tiled roof has been raised higher above the vault of the chapel in later years, thus cutting across and partly blocking the second storey window of the church at the ridge end of the chapel roof. The external wall of the church on the left side is devoid of any protective canopy other than the mouldings of the cornice at first floor and second floor levels. This has caused ingress of rainwater at the ledges, aggravated by the growth of weeds and moss at the cornice ledges. The roof itself has allowed leakage. The ground level outside the church has been raised over several successive developments and is now higher than the plinth level of the church. The drains along the church wall have been blocked up and no longer drain the rainwater away from the church walls. This has increased the rising damp in the left wall which has manifested itself through efflorescence in the cement plaster and wall glazed tiling on the inside of the nave. The glazed tiling with cement mortar has further prevented the drying out of the walls and caused the damp to rise higher. This ingress of salt laden rainwater has caused efflorescence, peeling of paint, disintegration of plaster, weakening and a total wipe out of the wall murals. The conflict of surface materials and the accompanying damage is shown in Figure 5.



Figure 5: Conflict of materials and damage on the surface of the inner walls of the nave.

## 4. RESTORATION OF ACOUSTICAL HERITAGE

### 4.1 Methodology

Each church, accommodating the conflicting conditions for sacred speech, sacred music, singing and silence in the sound decay [6] [7] [8], has a signature acoustical ambience which ideally optimizes the sacred liturgy in a worship space to become a genuine celebration of ‘comfort’ and ‘solace’ [9][10][11]. This is the acoustical heritage of a church. Nossa Senhora do Pilar church therefore, is supposed to have its unique acoustical heritage. This study was undertaken before the restoration work began, hence it captures the damaged acoustical ambience of the church. In order to facilitate the restoration of the acoustical heritage of Nossa Senhora do Pilar church, it was necessary to have a method of comprehensively characterizing the damaged acoustical worship ambience of the church as done in this study.

#### 4.1.1 Objective Acoustical Parameters

The objective acoustical parameters [Noise Ambience ( $L_{eq}$ ), Reverberation Time (RT), Loudness (G), Rapid Speech Transmission Index (RASTI) and Energy Time Graph (ETG)] were directly measured in four recording zones 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 [12], generated the following important objective monaural acoustic parameters: Definition [ $D_{50}$ ], Clarity [ $C_{80}$ ], Initial Time Delay Gap [ITDG] and Centre time [TS].

#### 4.1.2 Listeners and Music sources

Nineteen trained normal listeners were spatially seated into four seating zones within the church. Two locations in the church were chosen as music sources. The first location, labeled as ‘Music Source A’ (MA) was the floor of the north east nave – sanctuary corner of the church (ground floor) and the second location, labeled as ‘Music Source B’ (MB) was the floor of the choir loft of the church (first floor). The musical instruments that were tested in this church are cello (P), clarinet (Q) and an ensemble of cello, clarinet, violins and guitar (R). The locations of the music sources (MA and MB) and listeners seating for the subjective acoustic tests are shown in Figure 6. ‘SA’ and ‘SB’ are speech source locations (whose description is not in the purview of this study)

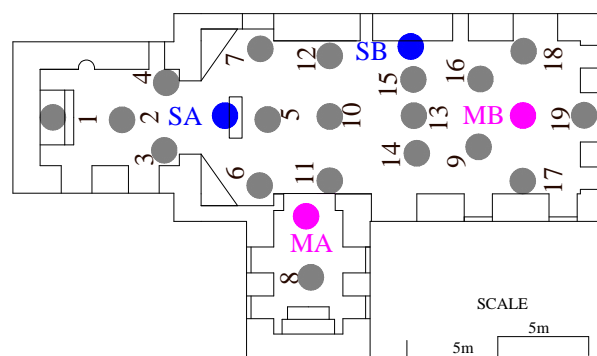


Figure 6: The location of listeners and music sources.



### 4.1.3 Subjective Acoustic Impressions

The acoustic evaluation sheet [13] given to the listeners was interpreted to accommodate parameters of worship. The listener, as guided before every test, judged to what degree the music played in the church was loud, clear, reverberant, well-directed, intimate, enveloping, tonally balanced, acoustically impressive and affected by echoes and background noise. The averaged scores of the acoustic qualities for different music sources and types in different seating zones of the church could be considered as subjective impressions the sound registered on the listeners. Therefore, the averaged scores of the subjective acoustic qualities were called subjective acoustic impressions (SAI) and are listed as: Subjective acoustic impression of Loudness ( $SAI_{LOUD}$ ); Subjective acoustic impression of Clarity ( $SAI_{CLAR}$ ); Subjective acoustic impression of Directionality ( $SAI_{DIR}$ ); Subjective acoustic impression of Balance ( $SAI_{BAL}$ ); Subjective acoustic impression of Intimacy ( $SAI_{INT}$ ); Subjective acoustic impression of Envelopment ( $SAI_{ENV}$ ); Subjective acoustic impression of Reverberance ( $SAI_{REV}$ ); Subjective acoustic impression of Echoes ( $SAI_{ECHO}$ ); Subjective acoustic impression of Background Noise ( $SAI_{NOIS}$ ) and Subjective overall acoustic impression ( $SAI_{OVER}$ ).

### 4.1.4 Acoustic Worship Indices [14] [15]

The religious experience denoted by the *Sacred Factor* (SaF) was comprehensively constituted by the mix of the acoustical parameters  $SAI_{REV}$ ,  $SAI_{INTI}$ ,  $SAI_{ENV}$  and  $SAI_{OVER}$ . It was hypothesized that the perception of the overall subjective acoustic impression ( $SAI_{OVER}$ ) has a tone of reverential awe and a subtle urge for the Divine when it is accompanied by a sufficient bonding with the source ( $SAI_{INTI}$ ) and a sense of being immersed ( $SAI_{ENV}$ ) into a vibrant ambience ( $SAI_{REV}$ ). All the constituent parameters were normalized and (as it was hypothesized that no weighting of the constituents was required) the arithmetic mean of the normalized values of subjective acoustic impressions of reverberance ( $nSAI_{REV}$ ), intimacy ( $nSAI_{INTI}$ ), envelopment ( $nSAI_{ENV}$ ) and the subjective acoustic overall impression ( $nSAI_{OVER}$ ) was hypothesized to be the subjective sacred factor (SSaF).

The religious experience denoted by the *Intelligibility Factor* (InF) was comprehensively constituted by the acoustical parameters  $SAI_{LOUD}$ ,  $SAI_{CLAR}$ ,  $SAI_{DIR}$  and  $SAI_{BAL}$ . It was hypothesized that the music played in a church had to be perceived as loud ( $SAI_{LOUD}$ ), clear ( $SAI_{CLAR}$ ), well-directed ( $SAI_{DIR}$ ) and balanced ( $SAI_{BAL}$ ) in its bass and treble tones, in order to satisfy the conditions of intelligibility of sacred music. Again, it was hypothesized that no weighting of the constituents was required as explained in the case of the SaF, hence the arithmetic mean of the normalized values of  $SAI_{LOUD}$ ,  $SAI_{CLAR}$ ,  $SAI_{DIR}$ ,  $SAI_{BAL}$  and SSI was hypothesized to be the subjective intelligibility factor (SInF).

It was hypothesized that in order to optimize the effect of music in the sacred liturgy an ambience of silence was necessary; therefore, subjective impressions of echoes ( $SAI_{ECHO}$ ) and background noise ( $SAI_{NOIS}$ ) were undesirable. These subjective parameters when normalized were converted and construed as positive determinants of the silence ambience and as such constituted the religious experience denoted by the *Silence Factor* (SiF). As, no weighting of the constituents was required, the arithmetic mean of the normalized values of subjective silence from echoes ( $SS_{ECHO}$ ) and subjective silence from noise ( $SS_{NOIS}$ ) was hypothesized to be the subjective silence factor (SSiF).

The subjective acoustical measures were evaluated on a semantic differential rating scale with seven points (1 to 7). For instance, loudness (overall loudness of the sound) was scaled from 1

(extremely weak) to 7 (optimally loud); Therefore, for the normalization of the DSAI the optimal reference limit value was taken as seven and their normalized values calculated using Equation 1,

$$\begin{aligned} nX_{\text{DSAI}} &= 1 & \forall X_{\text{meas}} &= X_{\text{ref}} \\ nX_{\text{DSAI}} &= 1 - \frac{\Delta X}{X_{\text{ref}}} & \forall X_{\text{meas}} &< X_{\text{ref}} \end{aligned} \quad (1)$$

where,

$X_{\text{meas}}$  is the measured value of the subjective acoustic impression,

$nX_{\text{DSAI}}$  is the normalized value of the DSAI,

$X_{\text{ref}} = 7$  is the optimal reference limit value of the subjective acoustic impression,

$$\Delta X = |X_{\text{meas}} - X_{\text{ref}}|$$

The USAI were also given an optimal reference value equal to 7 considering the latter to be the maximum value that can be scored on the semantic scale used for the evaluation of the subjective acoustic parameters. However, these undesirable subjective impressions of echoes and noise were expressed as their respective equivalents in terms of subjective silence from echoes ( $SS_{\text{ECHO}}$ ) and subjective silence from noise ( $SS_{\text{NOIS}}$ ). Consequently, the normalized values of  $SS_{\text{ECHO}}$  and  $SS_{\text{NOIS}}$  were calculated using Equation 2,

$$nSS = \frac{\Delta X}{X_{\text{ref}}} \quad \forall X_{\text{meas}} \quad (2)$$

where,

$X_{\text{meas}}$  is the measured value of the subjective acoustic impressions.

$nSS$  is the normalized value of the subjective silence impressions ( $SS_{\text{ECHO}}$  and  $SS_{\text{NOIS}}$ );

$X_{\text{ref}} = 7$  is the optimal reference value of the subjective acoustic measures ( $SAI_{\text{ECHO}}$  and  $SAI_{\text{NOIS}}$ );  $\Delta X = |X_{\text{meas}} - X_{\text{ref}}|$

The subjective data was analyzed using *Excel* and *Origin 6.1*.

## 4.2 Results

### 4.2.1 Surrounding Noise Survey

A recording of the ambient noise as received inside the church at the center of the nave generated a curve is shown in Figure 7.

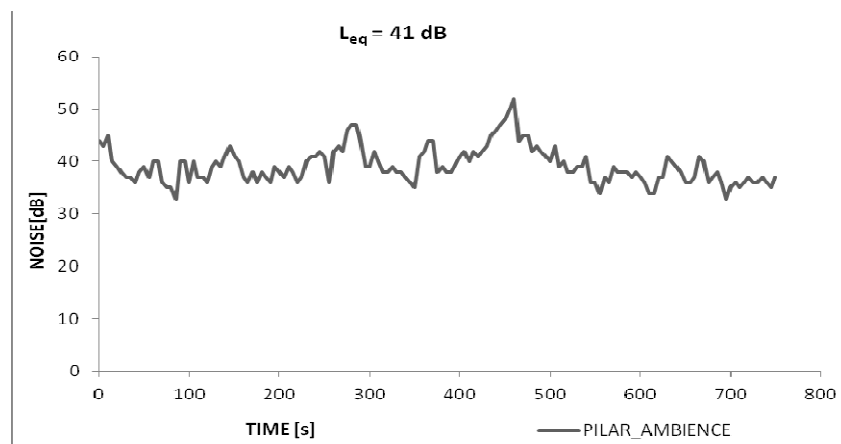


Figure 7: Noise ambient.

#### 4.2.2 Reverberation Time (RT)

The variance of the measured reverberation time in the different recording zones of the church is shown in Figure 8.

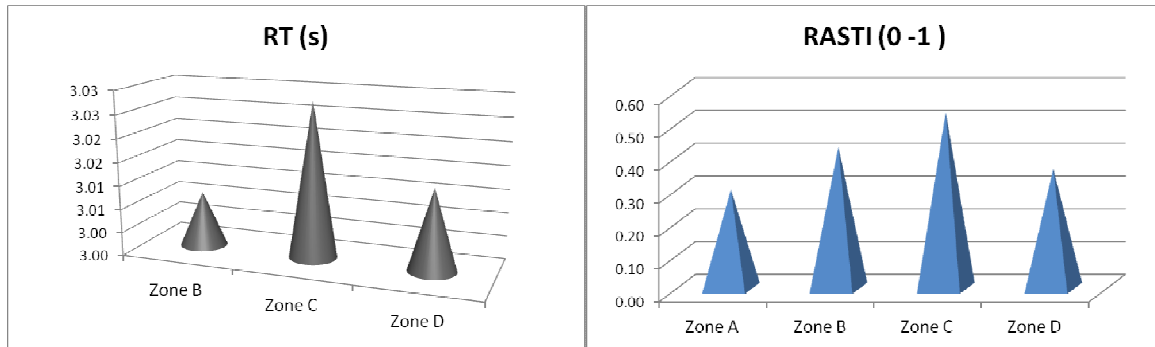


Figure 8: Positional Variance of RT and RASTI.

#### 4.2.3 Rapid Speech Transmission Index (RASTI)

The variance of mean RASTI values in the different recording zones of the church is shown in Figure 8.

#### 4.2.4 Energy Time Graph (ETG)

The ETG data as recorded by the ATB in the present study was for 119 equal intervals of 8 ms. From the ETG, the following monaural acoustic measures were obtained as shown in Table 2.

Table 2: Summary of the acoustic parameters calculated from the ETG.

Measured Acoustical Parameters		
Parameters	units	values
$G_{[MF]}$	dB	13.81
ITDG	ms	36
$D_{50}$	0-1	0.21
$C_{80}$	dB	-3.75
$T_s$	ms	250

#### 4.2.5 Acoustic Worship Indices (AWI)

The effect of different music source locations (within a church) and the effect of different music types on  $SSaF$ ,  $SInF$  and  $SSiF$  is assessed through the results of the ANOVA tests on the means of their populations averaged across 18 listener locations in the church as shown in Tables 3.



Table 3: ANOVA tests on means of AWI populations in the church (averaged across 18 listener locations in the church) to assess the tested church for different music types (P, R, S) at music source (MA) and music source (MB).

AWI	Music Type	Music Source (MA)		Music Source (MB)	
		Mean	p value	Mean	p value
SSaF	P	0.62	0.04	0.63	0.06
	Q	0.73		0.71	
	R	0.70		0.73	
SInF	P	0.66	0.05	0.66	0.01
	Q	0.76		0.79	
	R	0.66		0.78	
SSiF	P	0.67	0.54	0.75	0.13
	Q	0.62		0.67	
	R	0.66		0.72	

## 5. CONCLUSIONS

The following acoustical conclusions can be made from results presented above:

- The noise peaks levels in the church rose to around 50 dB. A value of  $L_{eq} = 41$  dB for the noise ambience implies that the damaged church had good ambience for silence and contemplation.
- Although the average reverberation time measured in the church was found to be 3.02 s, the nave of the church was found to be uniformly reverberant.
- The RASTI scores (indicating the suitability of the space for speech intelligibility) are not impressive (except in the the middle section of the nave to a fair extent).
- The obtained values of  $D_{50}$ , TS and  $C_{80}$  indicate that the clarity of sound for speech and music in the damaged church was poor.
- The obtained values of  $G_{MF}$  and ITDG [16] indicate that the church did'nt induce good subjective and objective intimacy.
- The means of SSaF in the church show the sacred music rendered from the choir loft by an ensemble of cello, violins, clarinet and guitars to be 94% significantly better than that rendered individually by either cello or clarinet ( $p = 0.06$ ). However the clarinet is 96% significantly better than either cello or ensemble in inducing sacred reverential awe when music was rendered from the floor of the nave ( $p = 0.04$ ) (Tables 3).
- In terms of subjective intelligibility required to let sacred music deliver the message and meaning (as characterized by SInF) the clarinet is preferred over cello and the ensemble for music rendered from the floor of the nave ( $p=0.05$ ), and even more when the rendition of the sacred music was from the floor of the choir loft ( $p=0.01$ ) (Tables 3).
- Subjective silence leading to sacred stillness (as characterized by SSiF) seems to preferentially favour neither cello nor clarinet nor the ensemble when music was

rendered from the floor of the nave; Although the cello seems to induce 87% significantly better effect from the choir loft of the church ( $p = 0.13$ ) (Tables 3).

These results will be compared with the results obtained through a similar acoustical analysis of the church after the wall surfaces are restored with original lime mortar mix and the nave floor is covered with compatible tiles and the intruding Art-Deco additions removed from the church (Phase II). Meanwhile, preserving and conserving the existing granite stone and wood motifs which are part of the surfaces, care has to be taken to ensure quality lime restoration of the wall surfaces and enhance the absorptive cum diffusive properties of the surfaces so as to restore the church to its proper higher intelligibility to speech and music.

## REFERENCES

1. Vatican II, 'Sacrosanctum concilium' (4 Dec. 1963, article 14, 34).
2. Pereira, J., 'Baroque India; The Neo-Roman Religious Architecture of South Asia: a global stylistic survey' (Aryan Books International, New Delhi, 2000).
3. Pereira, J., 'Churches of Goa' (Oxford University Press, New Delhi, 2002).
4. Lopes Mendes, A., 'A India Portuguesa' (Imprensa Nacional, Lisboa, 1886).
5. Cranfield, I., 'Art Deco House Style', (David & Charles, Devon, 2001).
6. Lubman, D., and Wetherill, E. A., 'Acoustics of Worship Spaces' (American Institute of Physics for the Acoustical Society of America, 1985).
7. Knudsen, V. O., and Harris, C. M., 'Acoustical designing in architecture' (John Wiley & Sons, New York, 1988).
8. Ettore, C., and Martellotta, F., 'Worship, Acoustics and Architecture' (Multi-Science, U.K, 2006).
9. Seasoltz, R. K., 'The House of God: sacred art and church architecture' (Herder and Herder New York, 1963)
10. Botton, A., 'The Architecture of Happiness' (Hamish Hamilton, London, 2006).
11. Tavares, M. A. P. S., Rajagopalan, S., and Sharma, S. J., 'Comparative Acoustical Studies of Two Goan Churches', *Proceedings of 19<sup>th</sup> ICA, Madrid (2007) paper rba-16-009*, Special Issue of the Journal *Revista de Acústica*, 2007, 38, 3-4
12. ISO-3382, 'Acoustics—Measurement of the reverberation time of rooms with reference to other acoustical parameters', International Standard Organisation, Geneva (1997).
13. Carvalho, A. P. O., 'Analysis of Subjective acoustic measures and speech Intelligibility in Portuguese Churches', *Proceedings of 131<sup>st</sup> Acoustical Society of America meeting 1996*, Indianapolis (USA).
14. Tavares, M. A. P. S., Rajagopalan, S., and Sharma, S. J., and Carvalho, A. P. O., "Acoustic Characterization of worship ambience – Old Goa's Capela do Monte, a comprehensive example," *Proceedings of 37<sup>th</sup> inter-noise 2008*, Shanghai (China), in08\_0526, (2008)
15. Tavares, M. A. P. S., Rajagopalan, S., and Sharma, S. J., and Carvalho, A. P. O., "Prediction of acoustic comfort and acoustic silence in Catholic churches," *Proc. 38<sup>th</sup> Inter-Noise 2009*, Ottawa (Canada) (2009)
16. Beranek, L. L., 'Music, Acoustics and Architecture' (John Wiley & Sons, Inc., New York, 1962).