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Acoustical Conservative Rehabilitation of St Roque Church, Tollecantto - Goa

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ABSTRACT

St. Roque Church, Tollecantto, Goa originally a Chapel was built in 1883. The conservation of the church edifice is in progress. Preservation of existing worship ambience is essential in any conservative rehabilitation of a heritage church. It is crucial to have correct reverberation time in the church so as to allow a simultaneous optimization of the worship space for speech and music. In this design, Reverberation Time (RT_{60}) of a sound signal inside the conserved church is established as a conservation reference parameter. Ideal Reverberation Time (RT_{60}) for St Roque church was calculated and found to be 1.33 s. Impulse Response Tests were conducted in the church for three different source positions (original High Altar; Existing Altar; Proposed altar) with recordings done at ten locations. Almost all the recording locations have recorded a RT_{60} value of 1.4s. Therefore, the value of measured RT_{60} = 1.4s is established as a reference yardstick to monitor the rehabilitative expansion of the church to accomodate another 150 faithful in the worship space.

Keywords: Acoustical conservation, Church, Reverberation Time

1. INTRODUCTION

St. Roque church, Tollecanto, Goa (*São Roque Igreja'* in Portuguese) was originally a chapel affiliated to St Francis Xavier Parish church, Velim. The chapel was built in 1883 and erected on June 18, 1885. This typical diminuted sanctuary village church of Goa shown in Figure 1, has a modest structure comprising of three bays and three storeys in Rococo Neo-Roman design (1,2). The nave acoustically couples with a diminuted sanctuary in the east and opens up to the congregation in the west through a coupled narthex on which seats an acoustically coupled choirloft. The gilded and gold platted Retable and side altars reveal some shades of neo-Gothic of the late nineteenth century.

Figure 1 – The pre-conservation looks of the façade and worship space within St. Roque church.

The contemporary need of accomodating more faithful in the church for liturgical celebrations prompted the stakeholders to look at options. One easy option was to build a new edifice or make

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lateral expansions into available circulation space around the church. However, a heritage church deserves a proper intervention that upholds the historicity and periodic aesthetics of the worship space (3). The intervention needs to be a defining moment for the faithful to celebrate restoration of their own faith experience (4). A holistic approach as such combines efforts to preserve the existing heritage character of the church while also exploring into the past to restore essential elements of the church heritage that have gone missing, with the present need for repairs and rehabilitation of the edifice. This study is part of a conservation plan presented as an alternative to rehabilitate the existing church for the present needs while conserving the character defining elements of this heritage church.

Conserving the unique architectural style of the church is imperative while designing a longitudinal expansion within permissible dimensional ratios.

2. METHODOLOGY

Monaural measurements of acoustical impulse response were carried out in the empty St. Roque church, in accordance with ISO 3382 set of standards, for three sound source positions (S1: Retable High Altar, S2: Existing Altar in Sanctuary and S3: Proposed Altar location under sanctuary arch) and for ten characteristic receiver locations. However, only those recording locations situated inside the church *per se*, are considered in this study (S1, S2, S3 - in sanctuary, three locations in nave and one in narthex) as shown in Figure 2a.

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Figure 2 – a) Existing Floor Plan of St. Roque church with marked locations of sound sources (S1, S2, S3) and recording locations (S1, S2, S3, 4, 5, 6, 7)
b) Floor plan of the Proposed expanded St. Roque church.

A passive loudspeaker with built-in powered mixer, Yamaha Stagepas 150 (Yamaha Corporation, Japan) was used. A directional speaker was used to simulate the real life situation in a church where a priest or lector or singer (human voice) is the sound source that emits energy into the worship space. The loudspeaker was set at an average height of a human person (160 cm) axially oriented towards the nave. Periodic Pink noise of 128k sampling length and 44100Hz sampling rate was used as the acoustical impulse released from the laptop based acoustical software ARTA version 1.9.2 (ARTALABS, Croatia and ASIO Interface Technology by Steinberg Media Technologies GmBH) along with M-AUDIO 2 audio interface (M-Audio, USA) and omnidirectional Behringer ECM8000 measurement microphone (Behringer, Willichm Germany). The recording microphone was set at 160 cm (average height of standing listeners).

The optimum Reverberation time calculations (5,6) were done for the existing St. Roque church and compared with the measured values of RT60. The possibility of fixing a reference RT 60 value was explored while expanding the church to accomodate a larger congregation. The proposed expansion of the church, as shown in Figure 2b, was done in harmony with the existing bay width of the church and had to accomodate the reference reverberation criteria. The optimal location for the altar was identified from the cumulative spectral decay, RT60 spectral analysis of the possible sound sources, positional variance of Loudness and Speech Intelligibility (7) and multiregressions of RT60 with other monaural acoustical measures. The acoustical analysis was done using ARTA 1.9.2, Microsoft Excel 2007 and Origin 6.1.

3. RESULTS

3.1 Cumulative spectral decay at multiple sources

The cumulative spectral decay for the impulses released from sources S1, S2 and S3 is shown in Figure 3, Figure 4 and Figure 5 respectively.

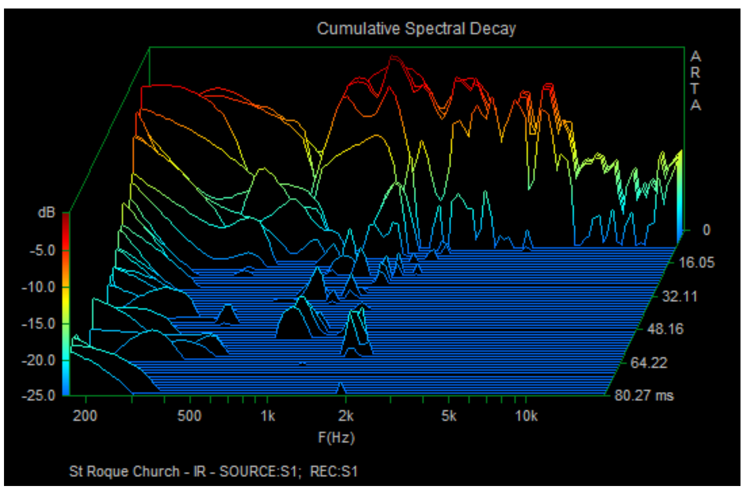

Figure 3 – The cumulative spectral decay at Source 1 (Retable altar location) in St. Roque church.

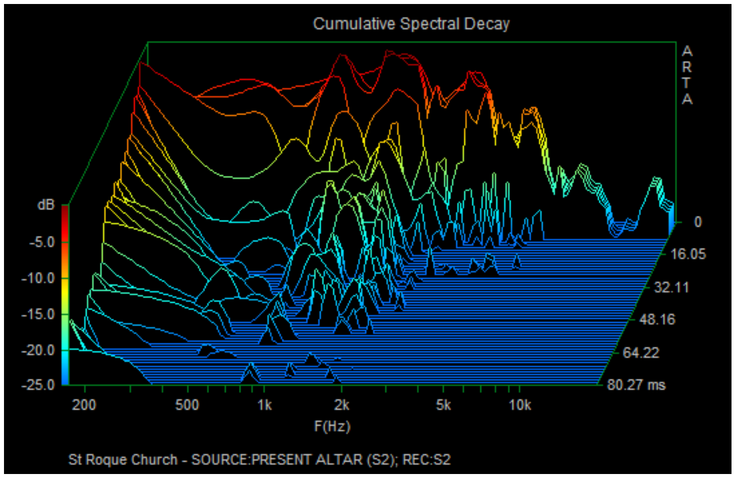

Figure 4 – The cumulative spectral decay at Source 2 (Present altar location) in St. Roque church.

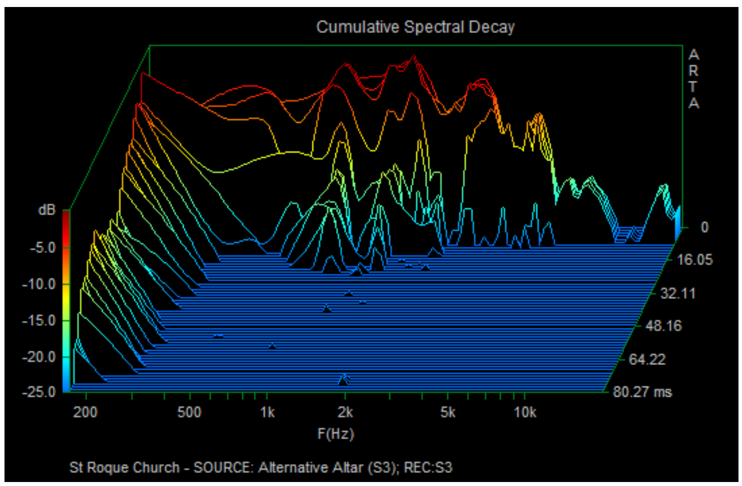

Figure 5 – The cumulative spectral decay at Source 3 (Proposed altar location) in St. Roque church.

3.2 Optimum Reverberation Time in a church

Using Sabine's formula for Reverberation time shown in Equation 1,

$$RT60 = \frac{0.049V}{S\alpha} \tag{1}$$

(where, RT60=Reverberation Time in seconds (s); V= volume of the church in cubic feet (ft^3); S= surface area of the church in square feet (ft^2); α = Average absorption coefficient of the church in sabine feet), and Knudsen and Harris' methods (5,6), optimum Reverberation time for St Roque church was calculated and found to be 1.33 seconds.

3.3 Multi-source positional spectral variance of RT60

The spectral variance of RT60 for S1, S2, and S3 at different recording positions in St. Roque church is shown in Figure 6, Figure 7 and Figure 8 respectively.

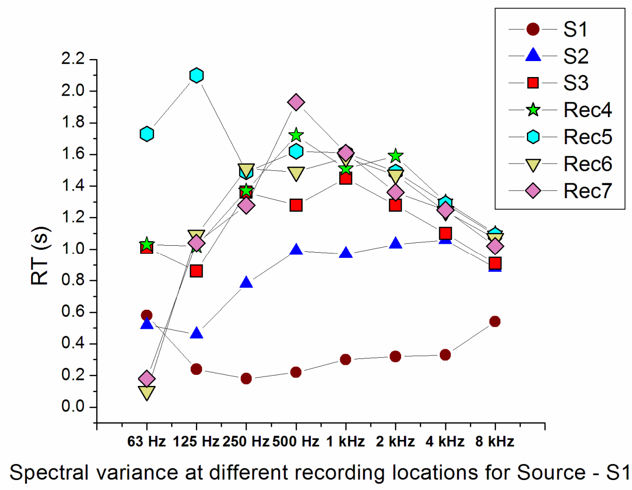

Figure 6 – Spectral variance for RT60 at Source 1 (Retable altar location) in St. Roque church.

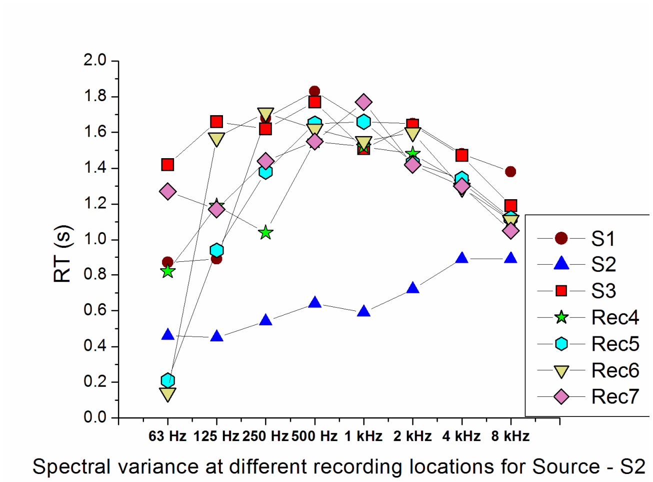

Figure 7 – Spectral variance for RT60 at Source 2 (Present altar location) in St. Roque church.

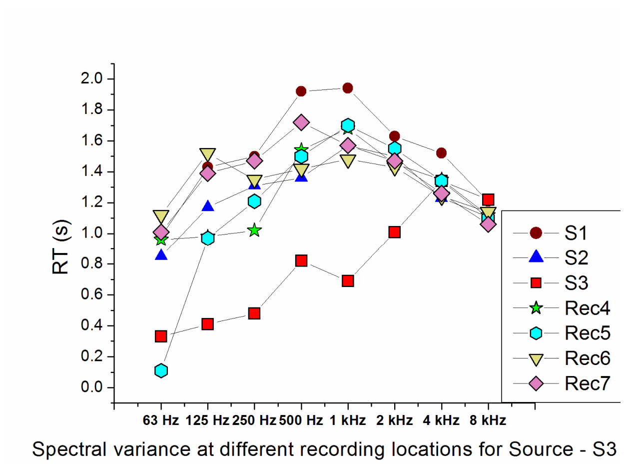

Figure 8 – Spectral variance for RT60 at Source 3 (Proposed altar location) in St. Roque church.

3.4 Multi-source positional variance of Loudness and Speech Intelligibility

The positional variance of Loudness (Leq) and Speech Intelligibility (RASTI) for sources S1, S2 and S3 is shown in Figure 9.

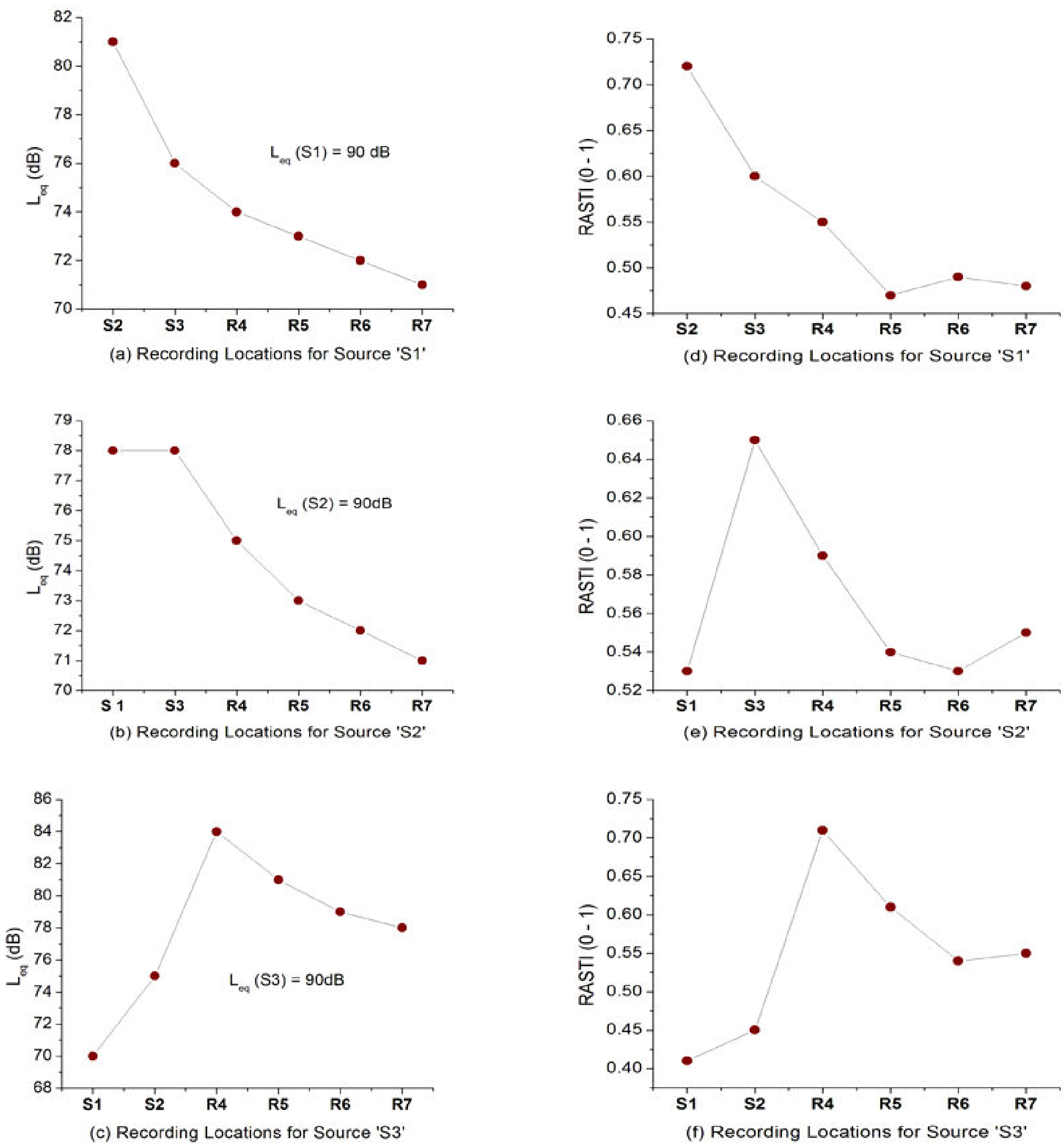

Figure 9 – Positional variance for Leq and RASTI in St. Roque church.
a) Positional variance of Leq for Source 1
b) Positional variance of Leq for Source 2
c) Positional variance of Leq for Source 3
e) Positional variance of RASTI for Source 1
f) Positional variance of RASTI for Source 2
g) Positional variance of RASTI for Source 3

3.5 Multi-Regressions of RT60 with monaural acoustical measures

The significant ($p \leq 0.05$) multi-regressions of RT60 with other monaural acoustical measures at different source locations are shown in Table 1.

Table 1 – Significant multiregressions of RT 60 with monaural acoustical measures

Rec. Loc.	PREDICTION EQUATION AT SOURCE 'S1'	R^2	p- value
S1	RT60 = 2.99 - 0.39EDT + 0.05C80 - 0.04D50 + 0.001TS	0.96	0.004
S2	RT60 = 1.18 + 0.70EDT - 0.02C80 - 0.004D50 + 0.009TS	0.97	0.01
S3	RT60 = -2.30 + 1.33EDT+ 0.11C80 + 0.01D50 + 0.01TS	0.94	0.03
Rec4	RT60 = 4.45 + 0.78EDT+ 0.18C80 - 0.06D50 - 0.015TS	0.98	0.007
Rec6	RT60 = -0.76 + 2.13EDT + 0.29C80 - 0.03D50 + 0.001TS	0.98	0.006
Rec7	RT60 = -0.12 + 1.42EDT + 0.07C80 - 0.01D50 - 0.002TS	0.998	0.02
Rec. Loc.	PREDICTION EQUATION AT SOURCE 'S2'	R^2	p- value
S2	RT60 = 6.9 - 0.11EDT + 0.02C80 - 0.06D50 - 0.03TS	0.9	0.03
S1	RT60 = -0.28 + 0.65EDT - 0.06C80 + 0.02D50 - 0.003TS	0.9	0.03
Rec4	RT60 = -0.49 + 0.56EDT - 0.10C80 + 0.02D50 + 0.004TS	0.98	0.001
Rec5	RT60 = 1.06 + 1.04EDT - 0.04C80 - 0.01D50 - 0.005TS	0.97	0.002
Rec6	RT60 = 2.16 + 0.29EDT + 0.03C80 - 0.015D50 - 0.004TS	0.85	0.05
Rec7	RT60 = 0.54 + 0.65EDT - 0.1C80 + 0.007D50 - 0.002TS	0.93	0.01
Rec. Loc.	PREDICTION EQUATION AT SOURCE 'S3'	R^2	p- value
S1	RT60 = 0.76 + 1.11EDT - 0.04C80 + 0.0015D50 - 0.007TS	0.998	<0.0001
S2	RT60 = 0.56 + 0.56EDT - 0.04C80 + 0.01D50 - 0.002TS	0.89	0.03
Rec5	RT60 = 1.18 + 0.83EDT - 0.04C80 - 0.007D50 - 0.006TS	0.96	0.04
Rec6	RT60 = 2.23 + 0.63EDT - 0.02C80 - 0.015D50 - 0.01TS	0.86	0.05
Rec7	RT60 = 1.42 + 0.9EDT - 0.1C80 - 0.003D50 - 0.01TS	0.99	0.0006

4. COMPARISON OF SOUND SOURCES IN ST. ROQUE CHURCH

The cumulative spectral decay at the Retable High altar location (Source 'S1') indicates a follow up of small magnitude in the frequency range of 1kHz - 2kHz upto around 60-70 ms. This improves at the existing altar location (Source 'S2') whereas at the proposed altar location (Source 'S3') the follow up restricts to a window of 30-40 ms. This suggests more strength and intelligibility in the signal emitted from 'S2' (cf. Figures 3-5).

At Source 'S1' impulse, RT60 showed assymetric higher values in the frequency bands of 63 Hz & 125 Hz (ranging from 1.7s - 2.1s) at Recording location'5' (in the middle of the nave) while averaging 1.29 seconds in the church. At Sources 'S2' and 'S3' impulses, RT60 showed a more uniform behaviour with the space responding a little more reverberantly, averaging 1.42 seconds in the church (for both the sources) Noteworthy observation is of the immediate frontal recording position 'S3' being the most reverberant (in most spectral bands) for Source 'S2' (cf. Figures 6-8).

While the impulse response at the back of the nave and in the narthex is quieter (in terms of Leq) for impulses from sources 'S1' and 'S2', the sanctuary becomes quiet for the impulse from source 'S3' (cf. Figures 9 a-c). The impulse from the existing altar location (Source 'S2') elicits comparatively better speech intelligibility (in terms of RASTI) in the nave and the sanctuary averaging 0.57 in the church (cf. Figures 9 d-e).

RT60 showed significant ($p \leq 0.05$) positive correlation with C80 and TS and showed significant negative correlation with EDT and D50 for source 'S1' recording at source point (S1). RT60 showed significant positive correlation with C80 and showed significant negative correlation with EDT, D50 and TS for source 'S2' recording at source point (S2). However at source 'S3', RT60 could not be predicted significantly from the monaural acoustical measures recording at source point (S2) and at recording position '4' (front-nave space). RT60 did not regress significantly with the monaural acoustical measures also at source 'S1' for Recording position '5' (mid-nave space).

5. CONCLUSIONS

Looking at the cumulative spectral decay at each source and the spectral behavior and significant multi-regressions of RT60 along with the wide band values of RASTI and Leq, the source 'S2' (existing altar location) seems to provide a better acoustical climate in the church in terms of good reverberance coupled with speech intelligibility and adequate loudness. Therefore, it is recommended to retain the altar location to its existing position.

As the average value of measured RT60 inside the church across all the sources was found to be 1.38 s, the conservative expansion of the church was monitored to keep the calculated reverberation inside the church within 1.40 seconds. The optimum reverberation time calculations (5, 6) for the proposed plan infact provides a RT60 value of 1.38 seconds. In this conservative plan, the width of the church (9.1m) is retained; importing the existing roof style of the sanctuary, the flat wood panelled false roofing of the nave at a height of 6.8m is changed into a trapezoidal wood panelled vault beginning at a height of 6.8m (on the eves) from the cornice level merging into a flat wood panelled plain/coffered roof at a maximum height of 7.9 m - this gentle raising of height negates the 'low ceiling' effect in the nave and the choir loft space; the length of the nave (inclusive of the narthex) is increased from 14.4m to 20.6m; Thus, the length/heigth ratio of the nave changes from 2.10 to 2.61; the heigth/width ratio of the nave changes from 0.75 to 0.87 and the length/width ratio of the nave changes from 1.57 to 2.26. The number of pews in the nave and the narthex of the church consequently increase from 26 to 38. This increase in pews will allow nearly 80 - 90 more faithful (calculating 8 persons/pew) in the nave and the narthex of the church. Atleast another 70 - 80 faithful will be accomodated in the additional 10 pews in the choirloft. In total, about 150 - 170 more faithful will thus get accomodated inside the proposed expanded church while retaining the acoustical worship ambience characterized by a reverberance of about 1.4 seconds.

Thus a thorough multi-source spectral investigation of reverberation as reflected by RT60 in relationship with other monaural acoustical measures was used as a working tool to acoustically conserve the worship ambience and aesthetics of St. Roque church while expanding it to accomodate more congregation. This investigation also endorsed the presently used altar position as the acoustically correct location for the altar in the church.

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