Solving the Acoustic Problem in Polyvalent Hall at Mauritius: Global Design Challenge Facing Larsen & Toubro, Limited

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Abstract

The architect for the Mauritius Auditorium project sat in his office at Larsen & Toubro's headquarters in Chennai, India, pondering the phone call he had just received from the vice president, Mr. K.P. Raghavan. The polyvalent hall of the conference center was about to be used to host its first rock concert in February 2005, but during a rehearsal the musicians complained about the sound quality being not up to expectations in the hall. Sound quality had not been an issue during the U.N. convention, but the louder music was causing problems, and a representative from Chuttur & Partners Limited, the company which managed the conference center, had called Larsen & Toubro wanting to know how to solve the problem. There had been no specific sound requirements when the center was conceived, and Larsen & Toubro was under no legal obligation to solve the acoustic problem. Therefore, a decision had to be made as to whether the company would work to solve the acoustic problem, and if so, how the problem could be solved.

Overview

K.P. Raghavan, Vice President of the Buildings and Factories Sector, Engineering Construction and Contracts Division, of Larsen & Toubro Limited (L&T) in Chennai, India, was invited to meet the Indian Ambassador to Mauritius, who told him that there was an opportunity for L&T to carry out a major project to build a new international convention center on the island of Mauritius. The conference center had to be ready in time for a United Nations meeting to review the implementation of the program of action for the Sustainable Development of Small Island Developing States that was to be held in Port-Louis, Mauritius, from the 10th to the14th of January, 2005. The budget for the project was Rs. 80 crores ($17.6 million)[1], and from conception to completion it was expected to take no more than 15 months. L&T agreed to undertake the project and the center was completed in time for the conference. Mr. Raghavan heaved a sigh of relief and relaxed as he listened to the video of the Secretary General of the U.N., Mr. Kofi Annan, delivering the opening address to the assembled delegates in the polyvalent hall in January 2005. This hall was originally intended to accommodate conferences, trade shows, exhibitions, seminars, sporting events, and concerts. It was built specifically to deal with a unique set of requirements and includes retractable chairs, adjustable lighting, and the ability to host multiple events simultaneously, as well as being very visually appealing. The Vice President of Mauritius was very pleased, saying, "This center will be one of the gems of Mauritian architecture, and will stand out as an example of Indo-Mauritian cooperation." Stephen Schwartz from the U.S. Embassy commented, "Fabulous building and quite an achievement."

A few weeks later, however, the architect for the project, Mr. Sukumar Hebbar, sat in his office at Larsen & Toubro's headquarters in Chennai, India, pondering the phone call he had just received from the vice president, Mr. K.P. Raghavan. The polyvalent hall of the conference center was about to be used to host its first rock concert in February 2005, but during a rehearsal the musicians complained about the sound quality in the hall not being up to expectations. Sound quality had not been an issue during the U.N. convention, but the louder music was causing problems, and a representative from Chuttur & Partners Limited, the company that managed the conference center, had called Larsen & Toubro wanting to know how to solve the problem. There had been no specific sound requirements when the center was conceived, and Larsen & Toubro was under no legal obligation to solve the acoustic problem. Therefore, a decision had to be made as to whether the company would work to solve the acoustic problem, and if so, how the problem could be solved.

Background

The Island of Mauritius

The small island of Mauritius is located east of Madagascar, a large island off the southeastern coast of Africa (Figure 1). Mauritius has a population of more than 1.2 million people and a land area of 718 square miles. The capital city, Port Louis, is located on the western coast of the island. The main form of currency on the island is the Mauritian Rupee. Mauritius has been self-governing since 1968, when it gained its independence from Britain.

A diverse collection of people from countries such as Europe, India, and China have created a unique culture in this country. English is the official language of Mauritius, but other languages spoken include French, Hindi, and Creole (a blend of French and English). The island's rich heritage means that its citizens practice many religions, including Hinduism, Christianity, and Islam. The island's diverse culture stems from

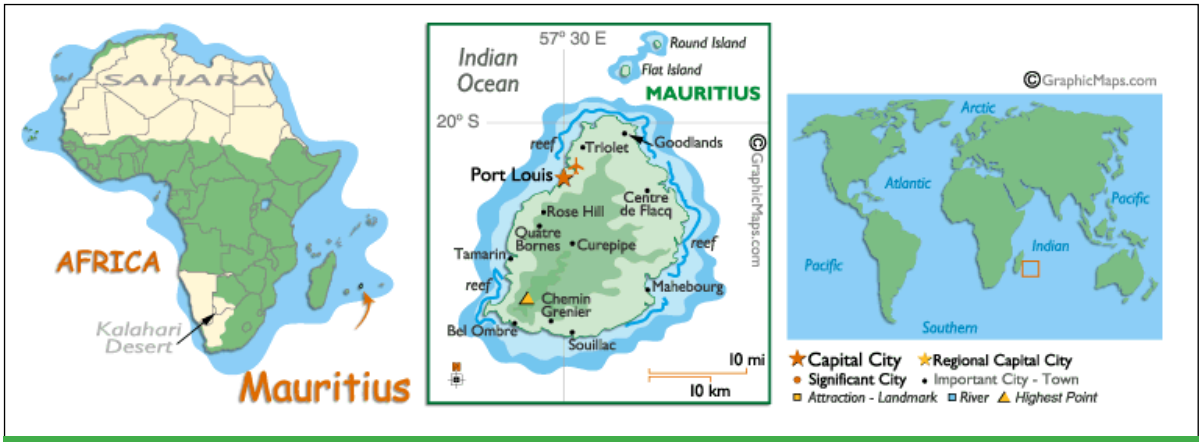

Figure 1 – Map of Mauritius.

the many ethnic backgrounds of the people that have settled on the island. This diversity can be seen in everyday life. For example, traveling through the island, one would not be surprised to find a Christian church located next to a Hindu temple. The work style on the island is very relaxed with most citizens working from 10:30 a.m. to 6:30 p.m. The rest of their time is spent mostly in leisure at the island's beaches.

The Relationship between Mauritius and India

India and Mauritius enjoy a special relationship that exists because of the long-standing cultural and political ties between the two nations. The location of Mauritius in the South-Western Indian Ocean enables this relationship between the two countries to prosper. Due to the closeness of the island to India, 68% of the island's population is of Indian origin. Mauritius and India's relationship is unique and includes relationships through common kinship, culture, religion, and interests. These commonalities and the island's strategic location have created strong political links between the two countries. The island has few natural resources and relies on tourism for growth.

Project Design and Construction by L&T

The initial purpose of the Swami Vivekananda International Convention Center was to accommodate the Meeting on Small Island Developing States, a conference for small island nations that is held by the United Nations once every four years. In addition to this conference, the convention center would need to be easily converted for other uses in order to generate revenue. The client for the project, Prime Real Estate Limited, requested that the project proceed from conception to completion in 15 months in order to meet the U.N. conference's deadline, which was originally August 2004 but was shifted to January 2005 at Mauritius's request. A Memorandum of Understanding for the financing the convention center by India was signed by the then Foreign Minister the Hon. A.K. Gayan of Mauritius and India's External Affairs Minister Shri (Mr.) Yashwant Sinha in October 2003

The close relationship between India and Mauritius encourages many Indian companies to do business on the island, and India's government was happy to extend assistance to the island for the construction of the international convention center. This center was expected to increase tourism on the island by making it an attractive center for international conferences. Four-fifths of the financing for the project was provided by the Indian government and the remaining fifth by the Mauritian government. The financing from the Indian government came half in the form of a grant and half in the form of a credit line. A leading Indian construction company, Larsen & Toubro, was invited to complete the project. The company accepted and joined Shapoorji Pallonji Ltd., another Indian company, to complete the project. This global design project was a major achievement because of the time, labor, and weather constraints involved with the construction. Because of the lack of building materials on the island, all resources for the construction of the center had to be shipped from India. The construction was also hampered by bad weather, including several cyclones. No work could be completed during such poor weather conditions, which created unpredictable delays in construction. In addition, the company struggled with cultural differences when using local labor, with their

Figure 2 – Conference being held during January 2005

more relaxed work attitude and culture. However L&T completed the work on schedule and to the satisfaction of the client.

The U.N. conference that convened in Port-Louis, Mauritius, was attended by 18 Presidents, Vice-Presidents, and Prime Ministers; some 60 ministers; nearly 2000 delegates, civil society representatives, and journalists from 114 countries; and representatives of 15 U.N. or multilateral agencies (Figure 2).This five-day conference hosted by the Republic of Mauritius was held as scheduled from the 10th to the 14th of January, 2005, in the impressive new conference center. (www.un.org/smallislands2005/).

Project Details

The site where the conference center was constructed measures about 13 acres and is located on a mountainside. The entrance to the convention center is complete with green landscaped mounds on each side of the entrance lined with royal palm trees to welcome visitors. The mounds were created to hide the 450 regular parking spaces for cars and coaches.

The complex is made up of a polyvalent hall, an amphitheater, a conference center, meeting rooms, a VIP lounge, and an atrium that doubles as a banquet hall. The center is to be used for meetings, conferences, sporting events, receptions, and trade exhibitions. To facilitate hosting different events at the center, retractable chairs, changeable lighting conditions, and the versatility needed to host multiple events were included in the design. The interior of the building follows a leaf design motif that is a symbol of the bounty of Mother Nature and represents the local culture. The outside of the building includes five columns that are shaped as trees, and the pattern on the floor inside follows the design of waves. As a result, the architecture of the building reflects the close interaction between nature and the island's culture and inhabitants (Figure 3). Further details of the architecture, along with photographs and information about the hall, are provided in the CD-ROM that accompanies this case study.

A Problem Arises...

As Mr. Sukumar Hebbar sat in his office at Larsen & Toubro's headquarters in Chennai, In-

Figure 3 – Outside View of the Conference Center

dia, he pondered the phone call he had just received from the vice president Mr. K.P. Raghavan. Mr. Hebbar was the architect responsible for the design of the Swami Vivekananda International Conference Center in Port Louis on the island of Mauritius. The problems at the site were handled by Mr. Gopinath, a senior architect at L&T. The project had not been without its setbacks, but the conference center had been completed by the January 2005 deadline. The multi-venue center had been universally praised for its beauty and functionality during the U.N. conference.

In the first stages of development of the conference center, a detailed design brief was provided to L&T by the client that laid out many of the performance requirements for the complex. L&T designed the polyvalent hall (Figure 4) with moderate absorption acoustic materials that would result in acceptable sound levels in the hall for the anticipated uses. However, the problem arose when the hall was used for a rock concert.

Business Ethics, Customer Relations

The Swami Vivekananda International Conference Center was constructed according to the design specifics agreed upon by the client in Mauritius. The acoustic problem was discovered later and Larsen & Toubro was not legally required to take care of this problem. Despite this, the executives of the company wanted to help solve the problem. For them, this was a matter of ethics, customer relations, and company pride. Since neither the company nor the client had addressed the issue beforehand, it was the position of Larsen & Toubro that it had a moral obligation to solve the problem. Mr. Rajan Venkateswaran, the chief architect in charge of the convention center project, said that "The client expects perfection, and it is our job to deliver it to them." This philosophy dictates that if a situation arises that causes the customer to be less than satisfied, L&T will strive to do all it can to rectify the situation.

To ensure success, companies must strive to maintain good relationships with their customers. For Larsen & Toubro, a company that often handles large projects like the convention center, this is particularly critical. Future business can be created or destroyed depending on the customer's satisfaction with the current project. Consequently, solving the acoustic problem in Mauritius wasn't merely ethical, it was also good business practice. Larsen & Toubro therefore did not hesitate to devote its resources to solving this problem. Chuttur & Partners Limited, Mauritius, the firm that managed the building, appreciated that L&T wanted to work with them to resolve the problem. L&T consulted with S. Rajagopalan Associates, the consulting firm that had provided the acoustic solution initially, to assess the problem. The consulting firm came up with several alternative approaches in order to rectify the condition. The acoustic consultant determined that the problem involved three major surfaces of the polyvalent hall: the back wall, the side walls, and part of the ceiling. L&T also asked Dr. A.

Figure 4 – Inside View of the Polyvalent Hall

Ramachandraiah, a member of faculty at IIT Madras, to evaluate the effectiveness of one of the materials that was suggested.

Concert Halls for Rock Music –A Review

Dr. Ramachandraiah reviewed the information he had gathered from numerous books and articles. Halls that host classical music concerts have benefited from years of acoustical research. Among audiences and performers alike it is well known that poor acoustics can ruin the joy of a musical performance, and both performers and audiences have been known to avoid a particular venue because of its unsatisfactory acoustical characteristics. The physical propagation of sound in these spaces is so complex that no table of numbers and no graphic simulation can easily model the quality of the entire acoustical experience.

Very few halls have been built specifically for rock concerts. Most are staged in existing buildings such as old cinemas or industrial buildings that find a new lease of life by hosting contemporary music performances[2]. One obvious feature that characterizes popular music performances is the use of powerful Public Amplifier (PA) systems. The sound pressure level (SPL) at rock concerts will often be well beyond 100 dB in the center of the hall several meters from the stage. Onstage, the sound sources are also radiating SPL of this magnitude in the frequency range of 40 Hz to 10 kHz towards the performers. Consequently, the final quality of sound in a hall depends on the sound system and its coverage in the hall.

Onstage, the performers want some early reflections from the walls, floor, and ceiling of the stage area. This is particularly true for acoustic performances such as acoustic jazz trios. Reflective surfaces will give the musicians a sensation of being connected in a natural and relaxed way. However, they generally prefer to avoid late reflections (e.g., from the back wall), as these often cause problems for drummers and other musicians who play instruments that generate short percussive sounds and may have difficulties "navigating" in a sound field dominated by late energy.

Nevertheless, a certain amount of support from the audience area of the hall is necessary. Too little is a source of irritation, giving the performer a feeling of not reaching the audience since he or she does not get a good sense of "being heard" nor of the response of the audience. The ideal reverberation time seems to lie within a certain "tolerance" range. If it is too long—that is, if late energy dominates—it introduces difficulties for the performers, and if it is too short, timing differences between the musicians will become too obvious, adversely affecting the confidence of the musicians. Audiences, and especially sound engineers, like to hear a precise, clear sound. Although a very short reverberation time might appear to be the answer, the audience may perceive this as a lack of vivacity, and it is also unclear whether audiences and performers agree regarding optimal reverberation times.

Rock music, jazz and other popular forms that are typically amplified require a relatively non-reverberant space. It helps if the interior space is large. If the sound energy at an amplified pop concert isn't dissipated quickly enough, the environment can become too loud. Ideally, the quality of the listening experience at pop concerts has more to do with the audio system than with the building's natural acoustics. A concert at 104 dB has ten times the intensity of a concert at 94 dB, which is a sizable difference. Given these considerations, the hall had to be designed to provide a good acoustic experience for both the performers and the audience[3].

Problem at Polyvalent Hall

The convention centre houses a polyvalent hall which is intended to accommodate concerts, gala receptions, trade shows, exhibitions, seminars, sporting events, and conferences. After the U.N. conference was over, the convention center was opened up for hosting these additional activities and thus generating revenue. Being a multifunctional hall, it was also expected to serve the different activities appropriately. Variable acoustic devices had to be installed in order to accommodate a wide variety of events and acoustical preferences.

A rock concert was planned at the polyvalent hall for February 11, 2005. During a rehearsal, the rock concert musicians found that the quality of the audio was not up to expectations. Gopinath, who was present at the occasion, measured the decibel level and found that the rock concert performed at a level of 104 decibels (dB), which was well above the original design level of 94 dB, and thatthis was likely one of the reasons for the discomfort expressed by the rock musicians. The polyvalent hall also suffered from high reverberation levels. The unexpectedly high-intensity sound levels due to the additional PA systems placed by the rock

musicians in front of the stage created some degree of overall acoustical discomfort, both on and off the stage[4].

The glass panel of the VIP gallery at the rear wall was also vibrating with a high amplitude, and listeners reported a lack of clarity and felt the sound to be distorted. Substantial portions of the back wall were bare and lacked any acoustical treatment. These areas reflected a part of the energy back towards the source, creating additional reflected energy. The reflected energy detected was both loud and late-arriving, resulting in multiple unwanted reflections. The clients wanted to resolve the issue as quickly as possible in order to avoid a lot of negative publicity.

Alternatives Considered

Alternative One

With limited time at their disposal, the acoustical consultant suggested that a locally available fabric be hung as curtains at specific locations on the wall surfaces as a stop-gap measure. This improved the situation and the concert took place the next day, February 11, 2005. The cost of this option was Rs. 5 lakhs ($11,000) and L&T bore these expenses. However, the client was looking for a permanent and more effective solution to this acoustic problem.

During his visit to the site, the acoustician found that the poor quality of sound was mainly due to high levels of reverberation. The hall required more absorption, and he felt that this could be resolved to a great extent by treating the rear wall, the back wall, and the ceiling portion. He provided a report that is available at the detailed case study available at www.liteecases.com. In order to maintain aesthetic continuity, the curtain would need to be of a specific color. The bright shade of orange needed for the fabric would need to be specifically requested, but the fabric could be acquired locally.

Alternative Two

The acoustician suggested a treatment using a fabric called Newtex, which is primarily a fire retardant material but also acts as a good acoustic material by modifying the scattering properties of the surfaces covered. The clients and L&T, however, wanted to verify the acoustician's claims regarding the material's properties. Hence, L&T approached Dr. Ramachandriah at IIT Madras with a request for material testing. The material exhibited an NRC (refer to the glossary) of 0.22 when tested with a hard backing. The acoustic consultant agreed that the values obtained at IIT's acoustic lab were similar to his own test results. Though the NRC value did not indicate the expected performance required for the polyvalent hall, the acoustic consultant recommended that Newtex would perform adequately if it was backed with two liner layers. The cost to implement this option was estimated at about Rs. 15 lakhs ($33,000). Details are available in the full case study available at www.liteecases.com.

Newtex, a material known primarily as a fire retardant, is a fiber glass woven and textured into a sheet of fabric form. It is non-flammable, non-toxic, and has mildew resistant properties. This fabric can be used as a sound absorber because of its ability to change the scattering properties of the surface onto which it is adhered. Newtex must be applied after first placing a layer or two of an absorbent liner onto the surface in question. Because this material is not regularly used as an acoustical material, its performance cannot be guaranteed. However, Newtex has been tested and was found to absorb sound. This material can be purchased in India and transported to the island.

Alternative Three

Meanwhile, L&T also approached Anutone Pvt. Ltd, which is well known for its acoustic materials and products. They referred L&T to SandyAcousTech consultants who came up with an alternate proposal to treat the hall. They guaranteed a reverberation time of 1.3 seconds by installing Anutone boards inside the polyvalent hall. This was sent for the clients' approval. L&T requested that their acoustic consultant verify the suitability of the Anutone boards. The acoustic consultant stated that it was a good option. However, the interior designer felt that with the use of the Anutone boards, the polyvalent hall would lose its aesthetic appeal and take on the appearance of a multiplex rather than an international convention centre. The cost to implement this option was estimated at Rs. 20 lakhs ($44,000). Details are provided in the case study available at www.liteecases.com

Anutone is a wood wool product made up of wooden shavings and other fibrous and porous materials. It is extensively used in many theatres and conference centers. It has been determined that Anutone, if installed in the polyvalent hall, could reduce the reverberation time at low frequencies from its current measured value of 2 seconds to approximately 1.3 seconds. In order to install Anutone boards, the laminate would first have to be removed from the required surfaces in order to reveal the framework onto which the boards can be fastened. Once the framework is located, the 600 mm2 panels could be attached with screws.

Finally, fabric would be stretched across the surface of the panels. Installation of Anutone panels is somewhat difficult, and its aesthetic appeal is low. Its performance as a sound absorber, however, met L&T's requirements. Anutone could be purchased in Bangalore, India, for approximately Rs. 1500 per square meter. The cost to transport it and install enough Anutone to cover the necessary surfaces (approximately 2000 meters) was approximately Rs. 20 lakhs.

Alternative Four

In the meantime the client and their consultants were also at work on their own solution to the acoustic problem. A cellulose spray was suggested by L&T's acoustic consultant. Details are provided in the case study available at www.liteecases.com. The cost to implement this alternative was estimated to be Rs. 30 lakhs ($67,000).

Because it comes as a spray, K-13 Asona spray can be easily applied on any wall or ceiling surface. The spray can be applied to a thickness from 6–25 mm. K-13 Asona Spray provides good sound absorption; at a thickness of 25 mm, the spray has an NRC value of 0.9. It can be flush with the surface intended for acoustical treatment. At nearly Rs. 30 lakhs, however, the cellulose spray was the most expensive of the available options. The spray option cost ten times more than what L&T had initially budgeted to solve this problem. The Asona spray had some aesthetic problems as well. The material had some color restrictions and the hall already had an existing color scheme. Mr. Rajan elaborated on this problem, stating that this spray is soft in nature and hence not good to be used on very close locations of the hall. Asona spray/ cellulose spray would have to be ordered from the United States.

Final Choice of the Client and L&T

The minutes of the meeting held on March 28, 2005, are shown in the detailed case study available at www.liteecases.com. The different alternatives had been proposed and now it was August 10, 2005. The client was anxious to decide on the final recommendation and implement it. Anil Chuttur, Director, Chuttur & Partners Limited, Mauritius and Mr. Elco de Jong, his consultant, had to develop a list of criteria to evaluate the alternatives and make a choice among the four alternatives. The client and L&T also had to decide who would pay for the modifications given that the acoustic performance requirements were not explicitly stated in the contractual documents.

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Glossary

Vibration: Vibration is a force that oscillates about some specified reference point. Vibration is commonly expressed in terms of frequency, such as cycles per second (cps), Hertz (Hz), cycles per minute (cpm) or (rpm), and strokes per minute (spm). This is the number of oscillations that occur in that time period.

Amplitude: The amplitude is the magnitude or distance of travel of the force.

Intensity: Intensity is simply the amount of energy transferred over a given area in a period of time.

Decibel: The decibel (dB) is used to measure sound level, but it is also widely used in electronics, signals and communication. The dB is a logarithmic unit used to describe a ratio. The ratio may be power, sound pressure, voltage, or intensity, or several other things.

The **difference in decibels** between the two is defined to be 10 log (P2 / P1) dB where the log is to base 10.

Longitudinal Waves: In a longitudinal wave the particle displacement is parallel to the direction of wave propagation.

Reverberation Time: The time it takes for sound to decay in a space is known as reverberation time.

(Endnotes)

1 An exchange rate of Rs. 45.45 for a dollar has been used in this case study. The exchange rate varies considerably.

2 (http://www.acoustics.hut.fi/asf/bnam04/webprosari/papers/o18.pdf)

3 The glossary provides definitions of terms used in this case study.

4 Similar problems were also identified in the acoustical studies done in seven Danish halls by Neil Werner Larsen and team, and it was revealed that the excessive use of PA in front of the stage combined with a long reverberation time in low frequencies was the main cause of this acoustic problem.

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Rajan Venkateswaran is the Chief Architect (Building & Factories Sector, EDRC) and was heading the Department of Architecture in the Engineering Design & Research Centre (EDRC), which is the Design & Technology arm of L & T ECC Division during 1998 – 2010. He has extensive experience in planning of various types of projects like Housing & Township, Institutional buildings, IT parks, multistoried office building, Transportation & Industrial buildings and Airports. He was trained by Japanese Firm (Shimizu Corporation) in the field of Architecture for period of 4 months at Tokyo. Presently he heads the Center for excellence and futuristic development which is focusing on enhancing energy efficiency, indoor environmental quality, occupant comfort and climate responsiveness in L&T's upcoming projects.

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Dr. Ramachandraiah Alur is a Professor in the department of Civil Engg at Indian Institute of Technology Madras. His areas of specializations are building Acoustics, noise control and building physics. He has guided several doctoral and post graduate students in the area of auditorium acoustics, noise control in buildings, thermal comfort and related functional area of buildings. He has several publications to his credit in both national and international journals and conferences. Some of his papers in conferences have won best paper awards. He had been actively involved in several collaborative projects with Auburn University. He is a fellow of Acoustical Society of India and a member of the Acoustical Society of America. Ha has been awarded silver medal for his contribution in Architectural Acoustics by the Acoustical Foundation for Education and Charitable Trust (AFECT).

Solving the Acoustic Problem in Polyvalent Hall at Mauritius: Global Design Challenge Facing Larsen & Toubro, Limited

Instructor's Manual

Learning Objectives

(a) Learn about the importance of acoustics in designing a large multi-purpose hall
(b) Identify the impact of decibel levels on human hearing and comfort
(c) Differentiate between alternate methods to fix the acoustic problem
(d) Study the importance of ethics in construction practices of a large construction company, considering the risks involved with project costs, material availability and performance

Possible Classes where the case study could be used

(a) Undergraduate classes in building science and architecture
(b) Graduate classes in building acoustics and noise control
(c) Undergraduate classes on functional design of buildings
(d) Undergraduate classes in business and engineering

Documentation of solution finally adopted by company

After an expenditure of Rs. 30 lakhs ($67,000) and substantial investment of engineering efforts, the acoustics in the hall has been improved significantly by using a sprayed-on material (K-13) of 16 mm thickness on either side of the speaker cluster that is hung centrally on the ceiling. The measured maximum sound level measured at the back wall was about 80 dBA, which improved the quality of sound to the level of "pleasant."

Connection to Theories in Acoustics

The reverberation time T of any large building is directly proportional to the volume of the enclosure and inversely proportional to the acoustic absorption present inside the building. In this case, the initial reverberation time before the reported problem was 2 seconds. This higher reverberation would have resulted in a higher sound pressure level at any given location inside the enclosure as per the room equation (refer to glossary). Therefore, one of the solutions is to increase the room constant (acoustic absorption) which helps in reducing the sound pressure level.

Possible Format for Class Discussion

This case study works best when assigned to a group of students. The groups defending the alternatives have to use both acoustical and non-acoustical factors (costs, risks, ethics) in their arguments. These groups could perform the following tasks:

(a) Group A: Defend the recommendation to implement the Second Alternative—Newtex.
(b) Group B: Defend the recommendation to implement the Third Alternative—Use of Anutone (wood wool product).
(c) Group C: Defend the recommendation to implement the Fourth Alternative— Use of cellulose spray (K-13).
(d) Group D: Represent the team of Chuttur and decide on the specific alternative that will be implemented. Provide both technical and non-technical reasons.

The suggested team format for classroom management of the case parallels the method used by corporate management to review current operations, forecast short- and long-term goals, and select a new operating system. The team approach also uses a divide-and-conquer approach, in that each team has a specific focus that will become part of the overall recommendation.

When the students research the case for explanatory answers to the questions, they will read through much of the background material included. This case study was designed to provide a very engaging and critical analysis of the case.

A possible approach is for the students to be given the case objectives and the questions to answer individually. This would give the instructor a basis for individual student evaluation. Once teams are formed and given specific assignments, team members could compare answers to questions relating to the team's assignment. If answers varied, team members would agree upon a consensus and could begin to talk together and come up with a proposed solution.

It would also be helpful for each team to prepare a formal presentation of the solution. This shifts the responsibility of determining the most appropriate format to use in presenting the solution to each team.

Short answers to Team Questions

Q.) Group A: Defend the recommendation to implement Alternative Two— Newtex.

Ans.) Newtex is a fiber glass woven textured sheet/fabric with non-flammable, non-toxic and mildew resistant properties. The specialty of this fabric absorber is that it can change the scattering properties of the surface onto which it is adhered with a layer or two of an absorbent liner. This results in reduction of formation of secondary reflective images. Its NRC value is 0.22. However its STC (refer to glossary) value is not

available. But its behavior in-situation has been quite satisfactory. The total cost of this material to be used in the polyvalent hall works out to be nearly $33,000.

Q.) Group B: Defend the recommendation to implement Alternative Three—
Use of Autone.

Ans.) Anutone is a wood wool product made up of wooden shavings and other fibrous and porous materials. It is extensively used in many theatres and conference centers. At the low frequencies, the measured reverberation time happened to be 2 seconds, and with the application of Anutone, one can reduce the reverberation time to 1.3 seconds in the polyvalent hall.
The cost to implement this option was estimated to be nearly $ 44,000.

Q.) Group C: Defend the recommendation to implement Alternative Four—
Use of cellulose spray.

Ans.) The material K-13 Asona spray can be applied on any wall or ceiling surface by spraying. The thickness of the material can vary from 6–25mm. The sound energy absorbing performance of K-13 guarantees effective noise control. The NRC (refer to glossary) value of K-13 at 25 mm thick is 0.9. It can be applied flush with the surface intended for acoustical treatment. Application of this product works out to be nearly $67,000.

Q.) Group D: Represent the team of Chuttur and decide on the alternative
that will be implemented. Provide both technical and non-technical reasons.

Ans.) From the economic view point, the first choice of using Newtex is preferable. But since it is not a regularly used acoustical material, its performance could not be guaranteed.

Costwise, Anutone product is preferable, but the use of Anutone boards may interfere with the aesthetic appeal of the polyvalent hall and the difficulty in applying it to various surfaces make it less preferable. The aesthetic look after the application may not be that great.

The application of K-13 spray works out to be the costliest option compared to the other two solutions, but the question is whether there is any specific advantage in using this material. Since its NRC (refer to glossary) value is somewhat higher and its application will not interfere with the aesthetic appeal of the hall, this solution could be preferred given the importance of the hall to the country.

Based on the above discussion, the group can develop a set of criteria. The criteria that could be developed are:

Aesthetics

The multipurpose center is to be used for meetings, conferences, sporting events, receptions, and trade exhibitions. To allow different events to be hosted at the center, retractable chairs, changeable lighting conditions, and the ability of the hall to host multiple events were included in the design. The interior design of the building followed a leaf design motif that is a symbol of the bounty of Mother Nature and represents the local culture. The inside pattern on the floor followed the design of waves. Thereby, the architecture of the building was chosen to reflect the close interaction between nature and the island. The acoustic consultant identified that the material would need to be applied on three major surfaces of the polyvalent hall: the back wall surface, sidewall surface, and ceiling portion.

The aesthetics requirement determines how appealing the alternative will be when applied in the hall. The alternative should blend well with the current design and surface architecture of the building. When considering the alternatives for this requirement the following should be considered: color options, texture, and design of the material.

Fire Safety

The safety requirement is based on the fire safety of the material. To evaluate the alternatives for this criterion, determine how safe each alternative will be in regards to fire safety standards.

Fixture Permanence

Chuttur & Partners Limited was interested in the most permanent solution to the acoustical problem. When evaluating the alternatives, determine the level of permanence each material has when applied to the hall surfaces.

Cost

Chuttur & Partners Limited and Larson & Toubro considered the cost of each alternative in their analysis for implementation. The cost criteria should be used to evaluate each alternative.

Performance

Larson & Toubro was faced with an acoustical problem. The performance of the hall was suffering for several reasons. First, the glass panel of the VIP gallery at the rear wall was vibrating with high amplitude. This caused the listeners to report a lack of clarity and to feel the sound to be distorted. Second, a substantial portion of the back wall was bare and without any acoustical treatment. This reflected a part of

the energy back towards the source, creating additional reflected energy. When the reflected energy detected was loud and arriving late it was resulting in unwanted reflections. The clients wanted to resolve the issue as early as possible. To fix the hall performance, L & T needed to apply materials that would have excellent acoustical performance. The criterion of performance is based on how well each alternative solves the acoustic problem.

Multipurpose Fixture Functionality

The convention center houses a polyvalent hall which is meant to accommodate concerts, gala receptions, trade shows, exhibitions, seminars, sporting events, and conferences. Being a multifunctional hall, it also has to serve the different activities appropriately. Variable acoustic devices have to be brought in, in order to accommodate, the increasing variety of events and acoustical preferences. Among audience and performers alike it is a well-known fact that to a large degree bad acoustics can ruin the joy of a musical performance. In fact, both performers and audience sometimes choose not to go to a venue because of unsatisfactory acoustical conditions. When evaluating this criterion one needs to determine if the material will work well in the multipurpose environment. Because sound levels will vary, the material will need to perform well in various events, including rock concerts, classical concerts, and business conferences.

Ease of Implementation

L&T needed to implement the alternative as soon as possible. This criterion evaluates the complication of installation of each alternative. This would include the skills, knowledge, and labor involved in implementing each alternative.

Shipping Method

The materials described in each alternative must be able to arrive at the island of Mauritius in a timely manner. This criterion considers whether there are any special shipping arrangements associated with each alternative. You need to consider whether the installation of the alternative could be delayed due to import/export regulations or customs and the distance involved in its travel to the island.

Based on these criteria, Table 1 compares the alternatives. L&T and Chuttur and Partners, Limited can use these in making their final decision.

Criteria	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
Aesthetics	Not Appealing	Okay	Did Not Blend With Interior	Aesthetically Appealing
Safety (fire)	Unsafe	Fire Retardant	Further Treatment Required	Okay
Fixture permanence	Temporary	Okay	Very good	Good
Cost	$11,000	$34,000	$44,000	$67,000
Performance	Okay	No Guarantee	Good	Best
Multipurpose fixture functionality	No	Yes	No	No
Ease of implementation	Easy	Involves Skilled Labor	Involves Skilled Labor	Easy
Shipping	Not Required	Required	Required	Required

Table 1: Comparison of the Alternatives on Eight Criteria