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3D Simulation Software for Mauritius Auditorium Acoustic Design

Prepared for
Swami Vivekananda International Convention Center
Mauritius Auditorium
Pailles, Port Louis _ Mauritius

Nov 22, 2010

Prepared by
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A.K. Gayan  
Vice President of Mauritius Auditorium  

24 November, 2010

A.K. Gayan  
Swami Vivekananda International Convention Center (SVICC)  
Pailles, Mauritius

Dear Mr. Gayan:

Thank you for providing L&T the opportunity to submit a proposal on the Mauritius Auditorium Acoustic Design project. With the company’s great access to the state-of-the-art 2-D and 3-D CAD facility with sophisticated plant design systems and basic engineering capabilities, we are presenting a solution by applying 3D simulation software for acoustic control, which we hope will yield both immediate and long term results. Our 6-month plan proposal to execute the project with our 3D simulation software is expected to give a better control over the reflection and reverberation time of the sound system in different environments. This will improve the overall acoustic quality of the Mauritius Auditorium polyvalent hall. Our project will also provide an appropriate agenda for the better communication amongst the teams responsible for the project that will result the more effective acoustic design for the auditorium.

L&T uses a phased implementation methodology to ensure a disciplined and organized development effort, with regular checkpoints for client approval and internal quality control. At this point, we have evaluated the schedule, resources, and budget for this project.

We have enjoyed conferring with your team and are looking forward to working with you further on this exciting and important project. We hope this proposal will meet your business, technical and budgetary objectives. You can be assured that we are committed to delivering the highest value and expertise to the acoustic design of the Mauritius Auditorium.

We look forward to hearing your response to this proposal by 17 December, 2010. We will contact you in the next two weeks with a phone call to see if you require any additional information. Should you have any question before that time, please feel free to call us any time at (01-408)-693-0409, Monday through Friday between 9:00am to 5:00pm (PST).

Sincerely,

Khanh Dao  
L&T Team’s Researcher
3D Simulation Software for
MAURITIUS AUDITORIUM ACOUSTIC CONTROL
by Khanh Dao

Abstract
Mauritius Auditorium faced acoustic control challenge when a rock concert was held in the polyvalent hall in February 2005. The report showed that the hall delivered bad quality sound system because the designed acoustic system didn’t qualify the required reverberation range of loud music. To fix the problem, our L&T team proposes the use of 3D simulation software that can fully control acoustic reverberation time of the sound system in different environments. Planned to be developed in 6 months, our software will apply 3D computational graphics to assist 4 steps of acoustic simulation techniques such as ray tracing, beam tracing, path generation and auralization. These 4 steps will coordinate together in order to simulate the qualified reverberation for different sound environment. (Word count: 121 words)
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- Nanda Guruswamy
- Jerry Wong
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Works Cited
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Our Understanding

Business Context
In 2005, L&T agreed to carry out a major project to build a new international convention center on the island of Mauritius. 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 auditorium, a detailed design brief was provided to L&T by the client, which laid out many of the performance requirements for the complex. L&T designed the polyvalent hall with moderate absorption acoustic materials which would result in acceptable sound levels in the hall for the anticipated uses. However, a problem arose when the hall was used for a rock concert. During the rehearsal, the rock concert musicians found that the quality of the audio was not up to expectations. The performers and musicians did not find the sound quality appealing at the time of rehearsal. The clients were highly concerned about this. An acoustical consultant who was present at the occasion found that the lack of absorption on the surfaces of the hall was the possible reason for this problem. For L&T, a company that often handles large projects such as the convention center, solving the acoustic problem in Mauritius was not merely ethical, it was also good business practice. 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 four alternative approaches in order to rectify the condition. The acoustic consultant determined that the problem involved three major surfaces of the hall: the back wall, the side walls, and part of the ceiling.

Key Objectives
Our team must estimate the acoustical level required accurately and find the most effective solution approaches in order to ensure multifunctional sound systems which will work well in any type of event hosted.

Scope
Our project will involve:
1) Relating software in applying mechanics of acoustical design and acoustics engineering
2) Evaluate alternative solutions to a design problem using Decision Support System

Our project will not involve because our solution just focuses on the software part to fix the problem.
1) Dealing with engineering, other than evaluating and testing.
2) Helping future architectural design of the concert hall.
Proposed Solution and Pricing

Summary
Our team is proposing a 3D simulation program that incorporates many of the acoustic design techniques that we will propose later in the case study. By using the program, it will be the general basis of establishing a concrete solution to the acoustic design flaws within the Mauritius Auditorium. By training and hiring professional Acoustical Engineer's, they will see the fundamental acoustic flaws, with the programs that we have proposed, and will coordinate with the contractors to reconstruct the auditorium. Our proposed solution will required precise scheduling deadlines, as will be seen later in our case study, in order to maximize the efficiency in producing a pristine auditorium without acoustical flaws.

Pricing Summary
Provided that the budget for constructing the Mauritius Auditorium was estimated at a cost of $17.6 million US dollars, our estimated budget for fixing the acoustic flaws within the auditorium is far less than the projected cost of developing a whole new auditorium. An estimated budget for this case study is estimated by the following items:

1) Software to fix and remodel the auditorium's acoustic flaws – $14,000
2) Estimated cost of hiring an Acoustic Engineer over a 3 month time span $25,000 - $30,000
3) Estimated cost of hiring a contractor for the desired renovations – $1,220,000

Estimated Total Cost: $1,259,000 (Based on current pricing of 2010)
*All estimation is in US dollars.

Conclusion
A.K. Gayan, Vice President of the Mauritius Auditorium, commented in the proposal of designing the auditorium, “This center will be one of the gems of Mauritian architecture, and will stand out as an example of Indo-Mauritian cooperation.” The projected result of fixing the Mauritius Auditorium will vastly increase economical revenue for the island of Mauritius. Fixing the auditorium will generate a wide array of interest as it is now allowed for a multitude of events to be held within the Mauritius Auditorium. Repairing the auditorium will promote better relations to India and other nations as it can continue to be an auditorium for UN relations and meetings. The Mauritius Auditorium will now be able to promote many different kinds of events as the acoustical designs will now be fixed. The Mauritius Auditorium will represent a landmark achieve for the island of Mauritius.
Company Information

Larsen & Toubro Limited (L&T) is a technology-driven engineering and construction organization, and one of the largest companies in India’s private sector. The company headquartered in Mumbai, India. It has additional interests in manufacturing, services and Information Technology.

A strong, customer-focused approach and the constant quest for top-class quality have enabled the Company to attain and sustain leadership in its major lines of business across seven decades. L&T has an international presence, with a global spread of offices and advanced manufacturing facilities in India, China, Oman and Saudi Arabia.

L&T has an international presence, with a global spread of offices. A thrust on international business over the last few years has seen overseas earnings growing to 18 per cent of total revenue. With factories and offices located around the country, further supplemented by a wide marketing and distribution network, L&T’s image and equity extends to virtually every district of India.

History

Henning Holck-Larsen
(4.7.1907 - 27.7.2003)

Soren Kristian Toubro
(27.02.1906 - 4.3.1982)

The evolution of L&T into the country’s largest engineering and construction organizations is among the more remarkable success stories in Indian industry. The company was founded in Bombay (Mumbai) in 1938 by two Danish engineers, Henning Holck-Larsen and Soren Kristian Toubro - both of whom were strongly committed to developing India’s engineering talent and enabling it to meet the demands of industry. Beginning with the import of machinery from Europe, L&T rapidly took on engineering and construction assignments of increasing sophistication. Today, the company sets engineering benchmarks in terms of scale and complexity.
**Product and Service Offering**

**Engineering & Construction - Projects:**
L&T’s engineering & construction track record consists of successful implementation of turnkey projects in major core and infrastructure sectors of Indian industry. L&T has integrated its strengths in process technology, basic and detailed engineering, equipment fabrication, procurement, project management, erection, construction and commissioning, to offer single-point responsibility against stringent delivery schedules. Strategic alliances with world leaders enable L&T to access technical know-how and execute process-intensive large-scale turnkey projects to maintain its leadership position.

L&T’s core competencies in engineering include highly qualified and experienced personnel from various disciplines, state-of-the-art 2-D and 3-D CAD facilities with sophisticated plant design systems and basic engineering capabilities. L&T is the only Indian EPC company pre-qualified for executing large, process-intensive projects for oil & gas, refinery, petrochemical and fertilizer sectors.

**Heavy Engineering:**
L&T is acknowledged as one of the top five fabrication companies in the world, with engineering and manufacturing capabilities that are among the most sought after in industry. Operating at the high end of the technological spectrum, L&T has led Indian industry in introducing new processes, products and materials in manufacturing. L&T also has the logistics capabilities of fabricating and supplying over-dimensional equipment to tight delivery schedules. L&T’s globally-benchmarked workshops are located in Mumbai, Hazira, Baroda and Kansbahal.

**Construction:**
ECC – the Engineering Construction & Contracts Division of L&T is India’s largest construction organization. Many of the country’s prized landmarks – its exquisite buildings, tallest structures, largest industrial projects, longest flyovers, highest viaducts, longest pipelines … have all been built by L&T. L&T’s leading edge capabilities cover every discipline of construction – civil, mechanical, electrical and instrumentation. L&T has also expanded its focus to the Middle East, South East Asia, Russia, CIS, Mauritius, African and SAARC countries. L&T is also developing...
markets for its construction services in the Indian Ocean rim countries, Africa and Latin America.

**Electrical & Electronics:**
L&T is a major international manufacturer of a wide range of electrical and electronic products and systems. In the electrical segment, the Company is India’s largest manufacturer of low tension switchgear, and is rapidly establishing itself in international markets. Its products are widely sold in markets in Europe and Australia. Recently, L&T set up a new manufacturing base for high-end air circuit breakers in China. L&T also manufactures custom-engineered switchboards for industrial sectors like power, refineries, petrochemical, cement, etc. In the electronic segment, L&T offers a wide range of meters and provides complete control and automation systems for diverse industries. Medical equipment and systems manufactured by L&T include advanced ultrasound scanners and patient monitoring systems.

**Information Technology:**
Larsen & Toubro Infotech Limited, a 100 per cent subsidiary of L&T, offers comprehensive, end-to-end software solutions and services with a focus on Manufacturing, BFSI and Communications & Embedded Systems. It provides a cost cutting partnership in the realm of offshore outsourcing, application integration and package implementation. Leveraging the heritage and domain expertise of the parent company, its services encompass a broad technology spectrum, catering to leading international companies across the globe. It leverages the L&T parentage to also provide services in the embedded intelligence and e-Engineering space.

**Machinery & Industrial Products:**
L&T manufactures, markets and provides service support for critical construction and mining machinery. We offer surface miners, hydraulic excavators, aggregate crushers, loader backhoes and vibratory compactors. Each of them incorporate innovative technologies that translate into higher performance on the field. The Division’s broad spectrum of capabilities cover products that have established brand preference in major markets around the globe – China, the Middle East, Europe and USA.

**Functionally complete**
L&T have constructed many functionally complete buildings globally. We have set a standard for construction and achieved many high acclaim regarding our construction. L&T performance and success are evident with their achievements below:
Achievements of L&T

SOME OF THE MASTER PIECES FROM LARSEN & TOUBRO LIMITED

<table>
<thead>
<tr>
<th>SouthCity Residential Project, Bangalore</th>
<th>Arihant Towers, Chennai</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL &amp; FS, Mumbai</td>
<td>Bahai Temple, New Delhi</td>
</tr>
</tbody>
</table>

Mumbai Stock Exchage, Mumbai

Fig. 1.2. L&T Achievements in Construction and Engineering (By: James Yu)

L&T has accomplished number of world-wide noticeable achievements:

1. Built India's first indigenous hydrocracker reactor.
2. Built the world's largest continuous catalyst regeneration reactor.
3. Built the world's biggest fluid catalytic cracking regenerator.
4. Built the world's longest product splitter.
5. Built Asia's highest viaduct - Panvalnadi for the Konkan Railway.
6. Built the world's longest LPG pipeline.
7. Built the world's longest cross country conveyor.
Methodology

Our team utilizes a five step methodology to create timely, effective and efficient solutions. The methodology establishes a solid foundation for common understanding of the project approach and enables the disciplined delivery of the solution in structured, manageable phases. While the overall methodology remains the same, processes and deliverables are customized within the methodology to meet each project or client’s individual objectives. The five steps of the methodology are known as DISCOVERY, DEFINITION, DESIGN, DEVELOPMENT and DEPLOYMENT.

Discovery

Discovery is the process of identifying areas of opportunity based upon certain criteria. Often, in smaller engagements, Discovery and Definition result in a response such as a request for a proposal. In a larger engagement, Discovery may be a single, distinct phase which in turn leads to the definition of multiple projects. Fig. 2 below shows the path which we will proceed in order to achieve the final goal of this project.

<table>
<thead>
<tr>
<th>1. Key Activities</th>
<th>2. Key Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1. Appoint the interviews with L&amp;T manager for the further access to the current situations of the problems.</td>
<td>2.1. Assessment to the root reason that caused the unqualified sound systems in the polyvalent hall of the Mauritius Auditorium.</td>
</tr>
<tr>
<td>1.2. Talk with engineers in global and acoustical fields in order to gain the familiarity with the covariance in sound systems implementations and designs.</td>
<td>2.2. General approach through the analysis of L&amp;T experts and specialists to the problems.</td>
</tr>
<tr>
<td>1.3. Document, prioritize, and group key objectives.</td>
<td>2.3. Expected budgets used and final outcomes of the project in term of both technological and market contexts.</td>
</tr>
<tr>
<td>1.4. Identify the executive sponsor and project lead.</td>
<td>2.4. Contact information for executive sponsor and project lead.</td>
</tr>
</tbody>
</table>

Fig. 2. Discovery process of identifying key activities and key deliverables
Source: Case Study’s Research. (By: Khanh Dao)
Fig. 3. L&T Design templates for sound systems in polyvalent hall of Mauritius Auditorium

Source: Team’s Design (Data: Ranju & Sanka, 2005) (By: Khanh Dao)

All L&T project teams will have the L&T executive sponsor whose role is to ensure the quality of each engagement in the whole process. In the discovery phase, our team’s executive sponsor will work closely with us in order to ensure an accurate understanding of the client’s business, objectives and engagement results. This is accomplished through the key meeting with the L&T construction manager and the representative of Mauritius Auditorium, as well as through the technical interview with the engineers at all levels involved in the issues. This process will give us the most complete and up-to-date information of the current problems as well as the view of current state of communication between the engineers and management team. We require a complete cooperation and engagement with Mauritius Auditorium and L&T construction team during the whole Discovery period.
Our team has researched literature and associated materials in acoustical design. We have found several key factors that caused the unqualified reverberation level and bad sound systems in the Mauritius Auditorium.

Even though the architectural design for certain events is the main cause of those issues, it is determined that if the reverberation level and sound testing were estimated more accurately by the computational technique, the problems in sound system such as vibrating with a high amplitude, lacking of clarity, unwanted echoing, sound reflection and sound distortion would be minimized.

As the result of our finding in this research, our objectives for this projected are listed as the following:

### 3. Project Objectives:

3.1. Increase the overall quality of the sound systems in the polyvalent hall.
3.2. Improve the amplitude and reverberation level with the limited budget access.
3.3. Prevent damage to the existing material in the original architecture.

### 4. Project Methods:

4.1. Applied computer technique to estimate the reverberation and echoing level of the hall.
4.2. Evaluating multiple proposed solution and decide the method by using a Decision Support System.
4.3. Increase the effectiveness in the communication between the engineers are responsible for the acoustical design, the architects who are responsible for the design of the auditorium and the project managers who are responsible for the budget and time-line management of the whole construction.

Fig. 4. Main objectives need to be solved in Mauritius Auditorium Acoustic Design project.

Source: LITEE’s research. (By: Khanh Dao)

Fig. 5. Polyvalent hall lacks of sound absorption on the surface

Source: LITEE study case
After talking to some experts in acoustical engineering fields, our L&T team decided to do a brief research on the acoustic ranges for specific purposes to discover the core problem in Mauritius Auditorium design, which is the ability to handle the different reverberation time required for different events. The tables below show some concrete information of reverberation and amplified level of different acoustic sounds in different acoustic environment. This data will be helpful for our team to propose the most persuasive and efficient solution for the facing problems.

Table 1.1. Acoustic range in Cinema:

<table>
<thead>
<tr>
<th>Volume [m³]</th>
<th>1,000</th>
<th>5,000</th>
<th>10,000</th>
<th>20,000</th>
<th>50,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$RT_{max}$</td>
<td>0.55</td>
<td>0.7</td>
<td>1.0</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>$RT_{min}$</td>
<td>0.35</td>
<td>0.45</td>
<td>0.7</td>
<td>0.9</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 1.2. Acoustic range for Speech:

<table>
<thead>
<tr>
<th>Volume [m³]</th>
<th>1,000</th>
<th>5,000</th>
<th>10,000</th>
<th>20,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>0.7</td>
<td>0.8</td>
<td>.085</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Table 1.3. Acoustic range for amplified music (includes rock, pop, jazz and other western music):

<table>
<thead>
<tr>
<th>Volume [m³]</th>
<th>1,000</th>
<th>2,500</th>
<th>5,000</th>
<th>6,500</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>0.65</td>
<td>0.8</td>
<td>1.05</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Definition

The definition phase is intended to organize and prioritize objectives as well as establish scope for the project. In the smaller engagements, all or a portion of the Definition phase may be completed in conjunction with the Design phase, resulting in response such as this to a request for a proposal. In larger engagements, the Definition phase may be a single, distinct phase which in turn leads to the Design, Development and Deployment of one or more applications.

<table>
<thead>
<tr>
<th><strong>5. Key Activities:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1. Form a team and assign the task for each member in the team for the solution design.</td>
</tr>
<tr>
<td>5.2. Determine the functional requirements, programming software and resources needed for the coming evaluation of the alternative proposed solution.</td>
</tr>
<tr>
<td>5.3. Develop the step by step process and the time-line needed for each step of the proposed solution.</td>
</tr>
<tr>
<td>5.4. Document progress of the solution design and schedule the progress report to the project managers.</td>
</tr>
<tr>
<td>5.5. Finalize schedule.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>6. Key Deliverables:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1. Specified tasks and responsibilities.</td>
</tr>
<tr>
<td>6.2. Functional requirements of software and resources.</td>
</tr>
<tr>
<td>6.4. Agreement upon the schedule the engineer-management report.</td>
</tr>
</tbody>
</table>

Fig. 6. Definition phase organizing and prioritizing objectives for the project.
Source: Team’s Research (By: Khanh Dao)

In order to prevent miss-communication and loss of information through the neural network during the whole solution process, our team will schedule a direct meeting between management, engineering and construction team once a week. Also, during the meeting, members will receive a tasks form including the list of tasks needed to be finished for each week; and during the meeting, we will clarify every details of the chosen solution.

The graph in Fig. 7 below shows us in details how the work will be planned to execute. The testing and evaluating process has to be managed in detail for the project’s final accuracy.
Fig. 7. Process testing and evaluating acoustical designs for Mauritius Auditorium
Source: Team’s Design (By: Khanh Dao)


**Design**

In the Design phase, our team will work with the client to develop the concrete solution and technical requirement for the current situations of the issue. Based on the information collected in Discovery and Definition phase, our team found that the miscommunication between engineering team and constructor team is one of the main factors leading to the bad sounds detect systems and unqualified reverberation levels of the Mauritius polyvalent hall. Therefore, our team has come to the decision to apply a computer simulation and 3D graphics software in order to gain the quality of sound and vibration in the auditorium. The software will be applied in every step of testing and comparing the quality of acoustical materials used in the auditorium. We require all software, acoustical and construction engineers work as ONE team to keep an accurate record of every single step in the evaluating process.

7. **Key Activities**

7.1. L&T Software engineer team will do research on computer simulation and 3D Graphics to detect and evaluate the different levels of sound reflection and reverberation through different resulting 3D graphs.

7.2. Collaboration between software engineer and acoustical engineer in testing the suggested building materials by applying those computer programs above.

7.3. Conduct one or more design and specifications of the necessary functionalities of the materials and technical devices being used and report them to the construction/building team.

8. **Key Deliverables**

8.1. Illustrations and graphics of sound and vibration levels.

8.2. Evaluating tables of testing materials and specific style guides for each type.

8.3. Technical specifications.

Fig. 8. Design phase determining computer software and technical requirements in Mauritius Auditorium Acoustic Design.

Source: Team’s research (By: Khanh Dao)
Our L&T team decided to present some thorough research for a deeper understanding of the acoustic software and system we have planned to use. The graphs below show the concrete implementation order of each method and its effect on the overall acoustic environment.

**Computer Simulation and 3D graphics in acoustic design**

The system that was developed goes through a four phase operation. The four phases includes spatial subdivision phase, beam tracing phase, path generation phase, and finally an auralization phase. Each phase generates data towards contributing toward the beam’s propagation paths which is then synchronized with an interactive visual audio/video output. The system was implemented in C++ in a Windows environment. The test model was conducted on a simple 6 polygon box and also on a 10,000 polygon building and in all models in between.

*(By: Jerry Wong)*

Use 3D graphics to compute the path and direction of the sound system in the polyvalent hall of the auditorium. 3D software is the very first step which can be usefully applied in computer simulation for acoustic design and control. Figure 9.1 besides shows one of the options of how sound’s direction can be determined and calculated in 3D graphics.

Figure 9.1 “shows a visualization of this cube map raycasting approach. Each ray cast is traced through the virtual scene and its acoustic energy accumulated and stored per frequency band. At points of ray/object intersection, the local surface acoustic energy exchange is evaluated… Newly generated rays from refraction, transmission and/or reflection are further traced, until their possible energy contribution falls below a certain threshold… The cube map not only stores all incoming acoustic energy per frequency band, but also the ray’s direction and length. This information is later used for the final binaural sound signal synthesis,” *(Röber et al. 2007).*

**Fig. 9.1. 3D cube map in the ray tracing simulation method**

*Source: Röber et al. 2007*  
*(By: Nanda Guruswamy)*
Stage 1: **Ray tracing** with 3D graphics is a way to represent the path of waves through a system. Programs have been developed to create simulations that trace rays made by sound waves. The programs are able to find the acoustic energy of an area by mapping the waves through ray tracing simulations. Along with real-time graphic computation, the auralization pipeline system is also more efficient and has an overall better design than previous methods. This system evaluates interactions between rays and objects and stores it individually in a cube map. By using heat-related transfer functions, or HRTFs, the data in the cube map is filtered.

**Limitation:**

The only limitation with this system is that the program can only consider one diffraction ray per second. This limitation can be overcome however by running a longer simulation time. The auralization pipeline system will still be helpful in designing a room with suitable acoustics for multiple sound types because it can be used with real-time sound.
**Stage 2: Beam tracing method**

Fig. 9.3. Beam tracing method for 3D simulation in Acoustic Design.

**Stage 3: Path generation**

Path generation calculates the propagation sequences of all transmission, reflections, and diffraction from each beam reaching each of the receiver’s location. By using a logarithmic time searching algorithm, path generation finds the shortest distances of all each of the beams propagation pathways. Basically, by using receiver’s at different locations of the auditorium or building, it can represent sound by using beams that are transmitted, then reflected and diffracted by hitting solid objects. Like walls, the beams will be traced back to the receivers. The path generation can then model how sound in the building can be modeled.

*The two diffraction point (Di) are determined by equal angle constraints at the corresponding edges (Ei)*
Step 4: Auralization.

*Auralization is the process of rendering audible, by physical or mathematical modeling, the sound field of a source in a space, in such a way as to simulate the binaural listening experience at a given in the modeled space.*

![Diagram of auralization process](image)

**Fig. 9.5. The signal processing structure of the DIVA auralization.**
Source: Savioja, Lokki (2005) (By: Khanh Dao)

**Implementation method from 3D image source:**
1) Ordered of reflection
2) Orientation (azimuth and elevation angles) of sound source
3) Distance from listener
4) Incoming direction of listener (elevation angle in relation to the listener)
5) Set a filter coefficients describing the material properties in reflections
6) Required parameters for calculation of response from a diffracting edge in the case of an edge source
7) Late reverberations are pre-calculated based on measurement of room acoustic modeling.

After doing deeper research and evaluating the advantages and disadvantages of each method, our L&T team has come up with the solution in which those methods will be applied simultaneously in order to support each other to result a better acoustic design. The graph below shows our concrete proposed solution for this case study.
Mission to achieve an Acoustic Design that can be well-functioned for different purposes

Ability to fully control reverberation time and reflection of the sound systems
- Measure reverberation time and sound qualities overall
- Detect late reverberation and unexpected echoing/noises in the environment
- How the whole architectural design afford the acoustic system.

Applying software implementation for sound management purposes

Computer simulation
Step 1/ Ray tracing
Step 2/ Beam tracing
Step 3/ Path propagation
Step 4/ Auralization

Graphics support computer simulation to detect the functionality of sound systems.

3D graphics applied to detect the direction and level of sound systems in different stages

Testing software implementation to adjust the architectural design as well as adjust the functionality of software for the most effective use

Implementation from top to bottom of all steps to control acoustic system

Fig. 10. Page mock-up design of proposed solution using computer simulation and graphics design
Source: Team’s design
(By: Khanh Dao; Implementation: Jerry Wong)
Development

The client’s acoustic software management comes to life during the Development phase. The primary activity of this phase will be coding based on the agreed design under the supervision of the Lead/Manager developer. The coding process will be divided into two big parts:

**Part 1:** Coding for 3D graphics software, which is responsible for calculating the sound directions and relative reverberation time at each stage.

**Part 2:** Coding for auralization software, which will apply the result of graphics modeling in part 1 to adjust the sound field of the source in the modeled space.

<table>
<thead>
<tr>
<th>9. Key Activities:</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1. L&amp;T graphics engineer and graphics designers work together in order to modify the implementations and specific functionalities of 3D graphics computational software.</td>
</tr>
<tr>
<td>9.2. L&amp;T engineers implement the modules, code additional functionality and configure database access to build computer simulation software from the results collected in 3D graphics</td>
</tr>
<tr>
<td>9.3. Internal code review and matching up between two parts – graphics and simulation, in order to conduct a final software product.</td>
</tr>
<tr>
<td>9.4. L&amp;T will conduct one or more client walkthroughs of the site prior to user’s final acceptance.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10. Key Deliverables:</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1. Concrete status report between graphics computational team and computer simulation team for data and results.</td>
</tr>
<tr>
<td>10.2. Periodic status report to Project manager.</td>
</tr>
<tr>
<td>10.3. A tested acoustic control system ready deployment training and performance trials.</td>
</tr>
</tbody>
</table>

**Fig. 11. Phases leading to development cycle for 3D software simulation.**

Source: Team’s Design (By: Khanh Dao)
Fig. 12. Proceeding the coding and implementation process in development phase for 3D software simulation.
Source: Team’s Design (By: Khanh Dao)
In order to assist the coding process in the Development phase, our team decided to do some extra research on mathematical equations displaying the relationship between the sound directions with its reverberation time. These equations can be applied in our 3D graphics coding process to lead to the more accurate computational.

1. **The audible spectrum equation:**
   \[ A_{\text{spectrum}} = A_s = \sum_{j=0}^{9} f_j \]

2. **Acoustic energy flowing from/to/through a surface element per unit time:**
   \[ I(t) = \frac{dx}{dA} \frac{dt}{dt} \]

3. **Kinetic energy as the pressure source of a sound wave:**
   \[ E_{\text{kin}}(t) = \frac{1}{2} \frac{Mv^2}{V_0} dt = \frac{1}{2} p_0 v dt \]
   
   Where \( v \) is the average velocity of air particles, \( p_0 \) the average media density and \( \frac{Mv^2}{V_0} \) its mass per unit volume \( V_0 \).

4. **Reichart’s measure of clarity incorporated an early energy time of reverberation**
   \[ C_{80} = 10 \log \left( \frac{\int_0^{0.08} p(t) dt}{\int_0^{0.08} p(t) dt} \right) \]

5. **Ratio of lateral reflected energy fraction of reverberation**
   \[ L_r = \left( \frac{\sum_{t=5 \text{ ms}}^{80 \text{ ms}} r \cos \phi}{\sum_{t=0 \text{ ms}}^{80 \text{ ms}} r} \right) \]


6. **Reverberation time of the concert hall:**
   \[ T30 = 0.55s + 1.04 \times 10^{-4} V \text{ s/m3} \]
   where \( T30 \) is the desired reverberation time

Source: Adelman-Larsen et al 2010 p 255 (By: Jerry Wong)
Deployment

Once a suitable 3D simulation program is selected for the auditorium, the system will be integrated into the Mauritius Auditorium. The various project teams will work with the auditorium technical staff to maintain the system.

11. Key Activities
11.1. Mauritius Auditorium accepts the system

12. Key Deliverables
12.1. Signed Mauritius Auditorium manager acceptance document

Fig. 13. Deployment phase completion objectives
Source: Team’s research (By: Nanda Guruswamy)

In order to gain the most efficient product in terms of a timely manner and quality, our team recommends some necessary requirement before the tasks are divided to different team members. The following table represents listed requirements and the outcome if those requirements are followed:

<table>
<thead>
<tr>
<th>Proposed requirements</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Trained acoustic engineers and 3D software programmers work together during step1a in Development phase.</td>
<td>1. 3D graphics computational software displays exactly the relation between sound’s direction and 3D graphics.</td>
</tr>
<tr>
<td>2. Thorough communication between 3D software, simulation software and acoustic engineer team for step1b and step2 in development phase.</td>
<td>2. Simulation software applies 3D software and works efficiently in order to adjust reverberation time of the sound systems.</td>
</tr>
<tr>
<td>3. Construction team cooperates with the other team above during step3, testing software quality in different environment.</td>
<td>3. Apply computer 3D simulation to get the most appropriate acoustic materials for construction.</td>
</tr>
<tr>
<td>4. Project and funding manager have to keep track of every single record of each step in the project.</td>
<td>4. Keep the budget in control and guarantee the best final acoustic control products.</td>
</tr>
</tbody>
</table>

Fig. 14. Tables of recommended requirement before processing the project
Source: Team’s research (By: Khanh Dao)
Decided project on 3D simulation acoustic software design

Team managers meet weekly for making final decision on software simulation.

Manager of each team work together and report weekly for an efficient management during the process.

Engineer/ Software Manager

Construction Manager

Funding Manager

Report weekly to authorized manager

Report to manager for budget control

Software engineering team and construction team work together to test the accuracy and quality of 3D simulation software

WEEKLY ISSUES REPORTED

Project Manager

Notice:
3D graphics team and simulation team work together and report the issue to each other.

Acoustic and construction team cooperate with software team in testing process of the software.

Issues report to project manager and project manager handle the current expense of the project.

Acoustic Engineer Team

Construction Engineer Team

Tasks divided to engineer team who are responsible for acoustic material and architectural design.

Fig. 15. Deployment phase presenting how the tasks can be handled to develop 3D software simulation for acoustic control.

Source: Team’s Design (By: Khanh Dao & Nanda Guruswamy)
Team Biographies

Khanh Dao
Currently enrolled at San Jose State, Khanh is completing her B.S. in computer science and aspires to receive a master’s degree in Finance. By combining both degrees, she is drawn to apply for computer science in financing system. Khanh puts high value on good database for computer system. She states: “It would be travesty for any of our banking system to crash; that is why computer science and creating a good database system is very important.” While Khanh is not programming, she enjoys playing classical piano in her free time and helping out in the community.

Nanda Guruswamy
As a news section editor who designed pages for her high school's newspaper, Nanda developed an interest in graphic design concepts. After taking some programming class in C language, Nanda decided to choose computer science as her major in college to satisfy her desire to learn about graphical computation and design. Nanda is currently working on a class project using GUI Java interface imitating the game Mancala. Working hard in school, her goal is to broaden her knowledge in computer graphics to pursue her dream to become a software engineer at Pixar in a near future.

Jerry Wong
Jerry is a junior at San Jose State University whose interest in video games lead him to pursue a degree in Computer Science. Along with his university course work, Jerry is working on side project that involves a competition for the popular PC game Starcraft: Brood War. By using an open-source program called Brood War Application Programming Interface or BWAPI, Jerry will develop artificial intelligence which will utilize human tactics and strategies. Currently, he is researching strategies and tactics that he can use in creating these advanced artificial robots. Jerry plans to enter the competition 2011.

James Yu
At a young age, James became fascinated with the Computer Science world when his uncle, who was a Computer Engineer, introduced him to the addicting excitement of video games. Fast forwarding to today, James hopes to influence people by generating life changing software through Computer Science. James worked for companies such as Fry's Electronics, Corsair Memory and Baseline Engineering. Juggling with work and school, James also dedicates his time to many community service programs such as Meals on Wheels, Salvation Army, and helping out many of the less fortunate during the Thanksgiving and Christmas seasons.
Annotated Bibliography


Research Method: Case Study
Research Type: Experimental
Research Design: Cross-sectional

Abstract

According to Kleiner et al. (2000), "Auralization is the process of rendering audible, by physical or mathematical modeling, in such a way as to simulate the binaural listening experience at a given position in the modeled space" (p 2). The primary goal of this study is to describe the current status of the DIVA auralization system, which is a room built for research purposes on acoustic modeling suitable for both real-time and non-realtime acoustic rendering. The result shows that "at the best the quality, the listeners have been unable to distinguish between recorded and simulated sound tracks. The quality of auralization system will still improve due to more efficient computers and advances in the modeling techniques" (Savioja et al. 2002 p 3).

Introduction

The basis of this study relates to the design of an auralization system. The implementation in the field requires a good knowledge in digital signal processing and psychoacoustics. The research problem aims to lie on the design of acoustic modeling, 3D sound reproduction, and perceptually optimized filter design.

This study approaches two main concepts in auralization: perceptual modeling and physics-based modeling. The perceptual modeling is "computationally less expensive, and therefore it's widely applied in the entertainment industry such as modern PC sound cards" (Savioja et al. 2002 p 3). The physical-based modeling is used for more accurate simulation in the application, which is utilized with higher requirements such as acoustical design of concert halls.

Method
The first method of this study was to apply the parametric room impulse response rendering method for auralization system. The system modeling is divided into two parts. First, the image source method is applied to figure out the order of reflection, orientation of sound source, and set of filter coefficient describing the material properties in reflections. Second, the late reverberation is calculated based on acoustic measurements or acoustic modeling according to the properties of space.

The second method focuses on audio signal processing. According to Savioja et al. 2005, "Signal processing parameters have to be defined on a sample by sample basis. In DIVA auralization system, this is achieved by interpolating the signal processing parameters between the updates of auralization parameters" (p 4).

The third method is modeling in diffraction. The method calculates the impulse response from the source to the listening position through the edges designed between image source calculation and auralization process. The implementation was not practical in real time, but dynamic off-line rendering is straightforward.

Discussion

The results of listening tests show some noticeable achievement in auralization. “Signals having sustained total characteristics such as sound of a clarinet were judged with the best grade. With signals having transients such as the hit of snare drum the differences were clearly audible but on the average, they were evaluated to be natural sounding.” (Savioja et al. 2002 p 6).

Conclusion

Even though this study was designed back in 2002, I find it very useful for our case study on Mauritius Auditorium Design since it analyzed thoroughly the advantage and disadvantage of the current auralization system in different acoustic environments. We will apply the information about acoustic control modeling that has been gathered and tested in this study to develop an appropriate acoustical system needed in our case study.

**Research Method:** Case Study  
**Research Type:** Experimental  
**Research Design:** Cross-sectional

**Abstract**

Poletti (2010) states, "Acoustic design of auditorium usually involves the specification of the room geometry and boundary properties, and any additional acoustic elements such as reflectors and diffusers, to usefully direct sound to produce a desired subjective experience, qualified by measurable acoustic parameter" (p 1). This study describes an alternative acoustic controlling solution called active acoustic system using sound control devices such as microphones and electronic processors to create reflection and reverberation time in the sounds field.

**Introduction**

The main goal of this study focuses on the principles of active acoustic system used to achieve a required range of acoustic control. Since the acoustic properties can be changed due to the different wide-range of time and sound environment, "the design of active acoustic requires the arrangement of microphones to detect relevant sound and the choice of processors and loudspeaker position to direct it usefully back into the room to produce a desired set of acoustic parameters" (Poletti et al. 2010 p 2).

**Method**

This study considers two main methods for a deeper understanding of active acoustic control: in-line system and non-in-line system.

First, in-line system creates early reflections and reverberation from the sound sources on stage, and minimizes the sound feedback to the microphones. This system doesn’t provide the global enhancement of reverberation time, which might be disadvantage when the audience noise is required to be enhanced.

Second, non-in-line system uses microphones "distributed around the room to enhance reverberation time" (Kleiner et al. 1995). According to Poletti et al. 2010, "an active wall can be implemented by using a closely spaced microphone and loudspeaker to either reduced or increase the local wall surface absorption, allowing the natural room to be either increased or
reduced, respectively" (p 6). Non-in-line system is suitable for the global enhancement of reverberation radius from all sound sources. The system's problem is enhancing the early energy, because microphones systems cannot detect the sound early enough, or with sufficient amplitude.

Discussion

Poletti (2010) states, "the risk of active acoustic system is that they may produce unnatural artifacts that relate to their method of operation such as time in-variant system can produce coloration effects caused by the greater variance of damping factors of the modes in the enhanced room, and time varying systems can produce noticeable pitch-shifting effects" (p 7). However, active system still can be considered as one of the useful recent innovation in acoustical design because "active acoustics in emerging paradigm offer considerable benefits to owners and to the public, and it is likely that subsequent generation of listeners will be more accommodated to the presence of electronics in live performances, and perhaps even to expect the greater range of acoustic conditions they provide" (H-J.Braun(Ed) et al. 2000).

Conclusion

This study is very useful for our case study on Mauritius Auditorium Design since it describes both of the advantage and disadvantage of an active acoustic system that can qualify the requirement of acoustic control in different sound environment. Our team will reference the information and the testing results of the in-line and non-in-line systems in this study in order to build a sufficient solution for acoustic design.
Works Cited


In L. Savioja, T. Lokki, & J. Huopaniemi (Ed.), *International Conference on Auditory Display* (pp. 1-8). Kyoto, Japan: Academy of Finland: Helsinki Graduate School in Computer Science.