A PARAMETRIC METHOD IN ROOM ACOUSTICS SIMULATION WITH PERFORMANCE VERIFICATION

Real-time Ray Tracing Techniques in Parametric Modeling

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Abstract. Since not all architectural projects can be involved in performance design calculations or optimizations, this study aims to reduce user technical barriers and enhance the visualization of the evaluation process. This paper introduces a parametric approach to room acoustics simulation, offering an interactive interface for modeling and simulation. By using Rhino-Grasshopper as a real-time ray tracing interface, both the Image Source Method (ISM) and Early Scattered Method (ESM) are employed for ray particle rebound tracking and analysis. The feasibility and analysis of spatial acoustic assessment tools are explored through the combination of data visualization and open-source parameter design meth. This research diversifies spatial models using various modeling tools like Revit, ArchiCAD 25, Rhinoceros 3ds, and SketchUp. This approach enables the evaluation of the effects and disparities caused by different modeling systems on simulation calculations. Furthermore, this paper also highlights the potential optimization of the Building Information Modeling (BIM) design workflow process. The results underscore the relationship between improved simulation accuracy and the utilization of numerical calculations, referencing benchmark simulation software ODEON for data comparison and review.

Keywords. room acoustics simulation, parametric modeling, rhino-grasshopper, real-time analysis, ray tracing methods, SDG 9

1. Introduction

This research conducts the scrutinization of the rationale and system framework methods employed in room acoustic and ray-tracing computations. Simultaneously, the research addresses the nonlinear workflow challenges faced by designers, users, and researchers in their respective tasks (Tan et al., 2019). Furthermore, the previous intricate logic demands complex settings have come to access. Additionally, plug-in software for room acoustics and design optimization with Graphic User Interface (GUI) based workflow has eased the use and performance simulation works.

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1.1. ROOM ACOUSTICS SIMULATION

The interplay between material absorption and acoustic performance is pivotal. Both sound and material hold a crucial position and can yield divisive effects contingent upon the properties of the materials in question (Brandão et al., 2022). Studies dedicated to appraising and contrasting software configurations tailored for divisive room acoustic settings (Lombardo et al., 2020) and the progress in Computation Aided Design (CAD) and Algorithm Aided Design (AAD) provide access to material and simulation databases, previous studies, processes, and achievements as shown in Figure 1.

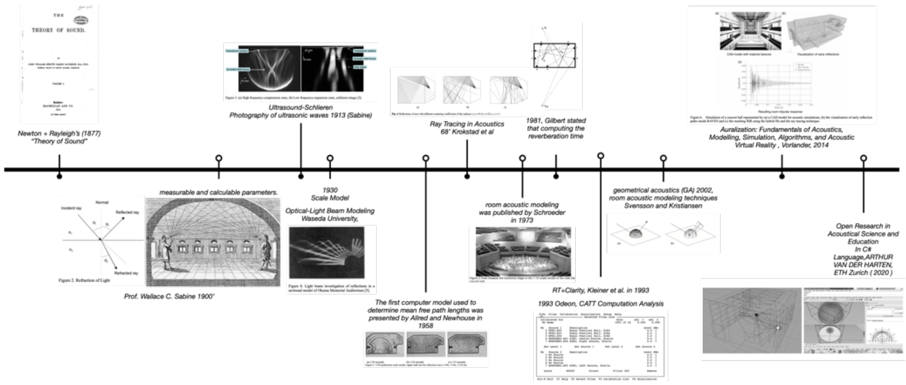

Figure 1. Studies in Room Acoustic Simulation and Measurement Methods

This research delves into the examination and development of boundaries and objective acoustic indices, as well as evaluation and computation methods. This exploration spans from the analogical era to contemporary algorithm-based calculations. The intention is to dissect the components of acoustic assessment and experimental approaches, providing insight and workflow into procedures underpinning the simulation of acoustic performance.

2. Background

2.1. GEOMETRY ACOUSTICS

The introduction of the Non-Uniform Rational B-splines (NURBS) algorithm (Echenagucia et al., 2013) provides a significant mark in room acoustics simulation. When assessing the impacts between sound and multidimensional surfaces (mesh-based 3D files), imperative the move beyond 2D Geometry-based computation. We re-examined and depicted the effects of NURBS operations on energy reflections from surfaces constructed with three-dimensional files. The scattering in three-dimensional variation states and energy intersection points disperses in a multi-dimensional pattern. NURBS algorithm has become a pivotal development in acoustics, particularly in the calculation of sound interactions with multidimensional surfaces, as highlighted in the work in Geometry Acoustics (Savioja et al., 2015). This necessitates departing from the previous confined 2D Geometry and employing three-dimensional surfaces composed of knots to influence energy reflection and utilization of the Rhino-Grasshopper modeling tool in room acoustic calculations (Bassuet et al., 2014), streamlines subsequent operations and research thresholds, enabling the calculation of 3D projections through the Rhino-Grasshopper plug-in method (Van der Harten et al., 2019), employed for ray-tracing geometry calculations in 3D Boundary Representation (BREP) based environment.

2.2. ROOM ACOUSTICS SIMULATION WORKFLOW

The process of performance-oriented design and simulation, followed by a nonlinear workflow, requires a complete rerun for adjustments in design. In the revamped design workflow, using a Python-based plug-in introduces a preliminary performance graph in the pre-modeling stages. Additionally, a genetic algorithm is employed for material optimization during software correction calculations. This approach allows the material search to be conducted from a performance-oriented perspective, avoiding the need to search for materials in the database individually. Significantly streamlines the entry into the Detailed Design (DD) phase, saving hours of repetitive searching and operation simulation by simplifying the searching of data and results. Workflow Optimization can be achieved by utilizing the INSUL Software system database and manufacturers' laboratory databases. The primary tools for acoustic performance at this stage include EASE, CATT, and ODEON Software. In this research, ODEON Room Acoustics Simulation Software 15 is employed for calculations based on geometrical acoustics. A combination of the ISM and the ray-tracing method is utilized for Algorithm-based acoustic simulations, incorporating visualization capabilities. Design changes within the indoor reflection, material absorption, and interface scattering coefficient also address various uses, musical performances, speech intelligibility, and loudspeaker system inputs, in which the physical parameters measured predominantly focus on sound rays, as shown in Figure 2.

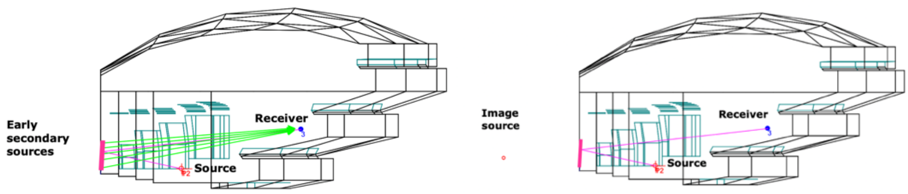

Figure 2. Ray-Tracing Methods in Geometry Acoustics (ODEON User Manual)

3. Research Methodology

Software for simulating and evaluating geometric acoustic performance has progressively advanced and matured. Utilizing computation simulations and the advantage of reducing the time and labor costs associated with constructing large-scale models for scaled tastings, thereby making performance design more accessible. Presently, room acoustics simulation relies on Geometry acoustic controls, which manage indoor reflection, material absorption, and interface scattering coefficients for various purposes such as musical performances, speech clarity, and input for speaker systems. The primary physical parameters measured pertain to sound energy. ODEON software stands out as a professional tool for audio performance simulation grounded in geometrical acoustics. Computer-based sound field calculations involve a combination of both ISM and ESM ray-tracing methods, with outcomes in sound dispersion that are then visualized for data visualization.

3.1. PERFORMANCE ORIENTED DESIGN AND MATERIAL

This research centers on spaces where speech intelligibility stands as the primary performance requirement, focusing on the exploration and establishment of Performance-Oriented Design (POD) principles for space dimensions and the treatment of indoor sound-absorbing materials such as ceilings, walls, and seating. Additionally, we presented the workflow and cycle of the BIM process. In this system, computer-aided simulation software, specifically ODEON and its derivative parameter tools, is utilized for simulation results, serving as a reference for data. This aids in understanding the optimization process of building planning design cycles and performance design, particularly for numerical comparisons related to voice clarity. Six distinct room types are scrutinized concerning verbal spaces. This research involves simulation and the impact of diffusion on the clarity of sound energy distribution between users and seats, particularly focusing on reflection's impact on performance design. It encompasses testing spatial design variations, evaluating their effects, and optimizing and enhancing the acoustic performance of verbal spaces.

Ceilings in interior design serve not only an aesthetic role but also play a crucial part in incorporating sound-absorbing materials into key areas of modern design vocabulary. This is achieved through a unitized design approach using a lightweight steel frame and sound-absorbing materials. The production design adheres to imported specifications, employing 35mm Wood Wool Cement Board (WWCB) with air gap. This strategy is devised to fulfill formal conditions, optimizing spatial performance in terms of the material's specifications and performance. The replacement of partition walls with multi-layered glass-based facades emphasizes the importance of wall performance and acoustic treatment. In the design of walls and facades, the upper wall is retained for accommodating electrical wiring, air conditioning, and equipment piping channels above door height. The material selection focuses on localized sound-absorbing treatment, utilizing aluminum-based acoustic panels to mitigate reverberation and sound reflection effects, enhancing speech clarity. The selection of seating arrangements is pivotal to the acoustic environment's performance. In this study, where the sound-absorbing material area was relatively limited, the visual presentation of the seat design significantly influenced its performance. The study relied on laboratory data from sound-absorbing seat manufacturers to comprehensively assess room characteristics and seat specifications, as illustrated in Figure 3.

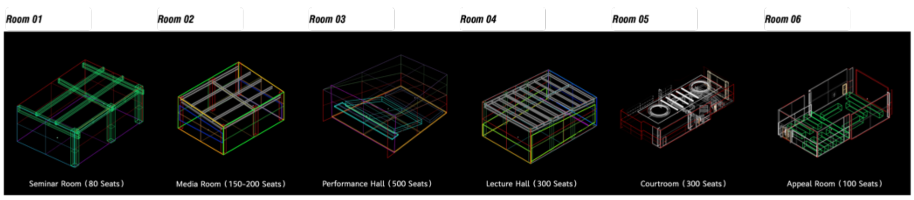

Figure 3. Room Typology and Characteristics for Acoustics Simulation

3.2. PARAMETRIC RAY-TRACING METHOD

Raytracing involves calculating the impacts of energy and particle paths using the ray method, with the energy particles diminishing after five impacts, as in the experimental setting. The utilization of derivatives significantly enhances the connection between performance and spatial design at the initial stage. This is achieved by promptly providing users with feedback data and visual patterns, aiding in their comprehension of the relationship between spatial configurations and performance. Additionally, it presents the numerical state of the content. The calculation results were sequentially presented at 63Hz, 125Hz, 500Hz, 1000Hz, 2KHz, 4KHz, and 8KHz. For initial data, algorithm-based & data-based simulation was employed. Through derivative tools, the relationship between performance and spatial design at the outset was markedly strengthened, offering users immediate feedback on data and visual patterns. This facilitated a clearer understanding of the correlation between spatial configurations and performance.

4. Room Acoustics Simulation

The use of the Rhino-Grasshopper interface has led to the modularization of algorithmic tools through plug-in tools, make easy for designers and firms to operate. By breaking down and reassembling the compositional steps of acoustic algorithms, it becomes feasible to sequentially acquire spatial design and acoustic performance graphics. This is achieved through the projective line method and surface calculation. The process allows for simulation and adjustments in parametric design mode, facilitated by the Grasshopper plug-in. This feature enables real-time modifications to the design, serving as a helpful reference during the Conceptual Design (CD) phases, simulation, and cross-interface workflow as shown in Figure 4.

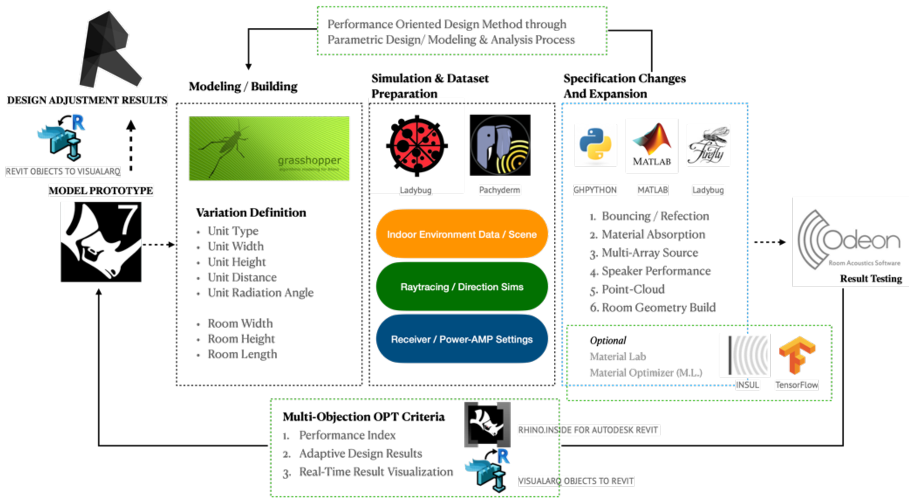

Figure 4. Software plug-in and Research Workflow

Reverberation Time Index (T30) and Clarity Index (C80) present calculated results with data visualization in the interaction between various software and testing methods for each room type. Comparing data from different software conducts use of standard deviation, revealing remarkably close standard deviation values in larger room types. One factor contributing to this was the modeling of seating in larger spaces to generate a greater surface area of sound-absorbing material. This aspect was thoroughly investigated in subsequent studies to validate the connection between modeling methods and the obtained data. In larger spaces, seats were specifically modeled to increase the surface area of sound-absorbing materials. The computational logic indicated that Rhino-Grasshopper-based surface calculation closely aligned with ODEON surface calculation when standard deviation was utilized as the accuracy metric for data comparison. The study found variations in data accuracy under different modeling tools and types, emphasizing the impact of the state and number of open-source tools on simulated values, settings, and methods as shown in Figure 5.

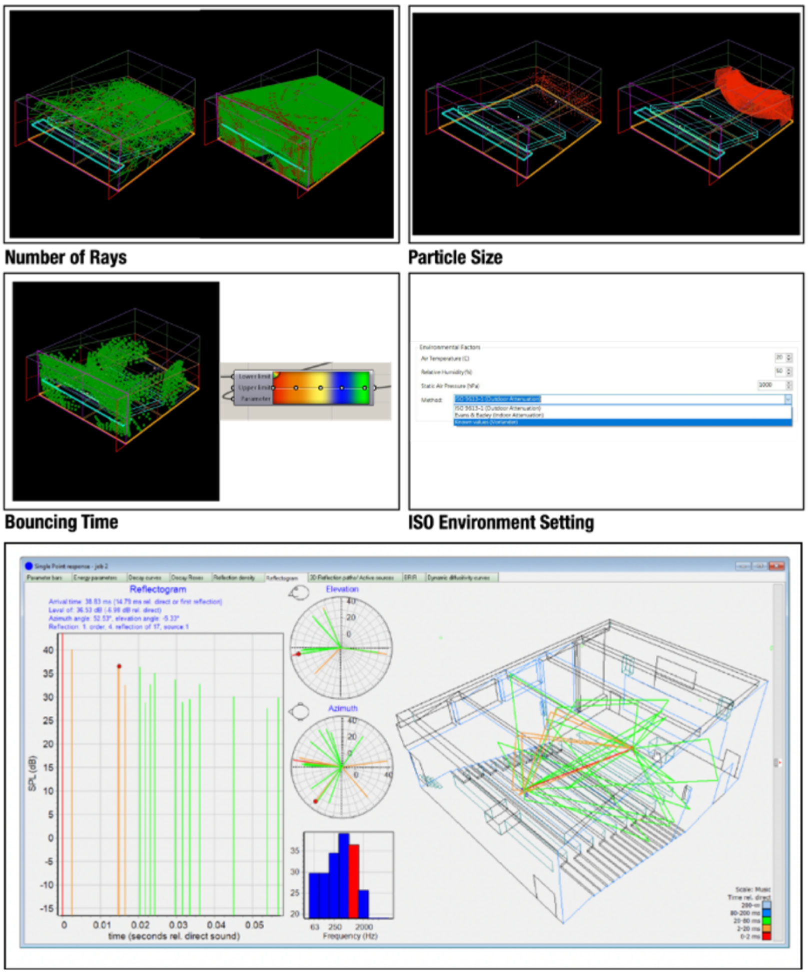

Figure 5. Ray-Tracing Acoustics Simulation in Rhino-Grasshopper and ODEON Acoustics Software

5. Results and Discussion

The software for simulating and evaluating the acoustic environment through geometrical acoustics. The ease of use in simulations offered the advantage of time and cost reduction and also physically scaled models and tests, thereby making performance design more accessible. In this study, the credibility of the tool and the results were established through comparison and examination of data between this tool and the ODEON performance software after presenting performance indexes. The ODEON software algorithm's simulation data and material library were derived from the material performance coefficient database. To standardize the control and influence of variables on reverberation time, the study compares the differences in reverberation time and clarity values between the two tools. This involves minimizing variable variations in control and parameter acquisition while focusing on the spatial performance of different chambers. Under identical material performance settings and configurations, the study assesses the differences in Reverberation Time Index (T30) performance, with data obtained from the interactive adjustment of different software and test methods for each chamber type. Comparisons of standard deviation in the data from different software revealed extremely close values, particularly in medium and large chamber types, results shown in Figure 6.

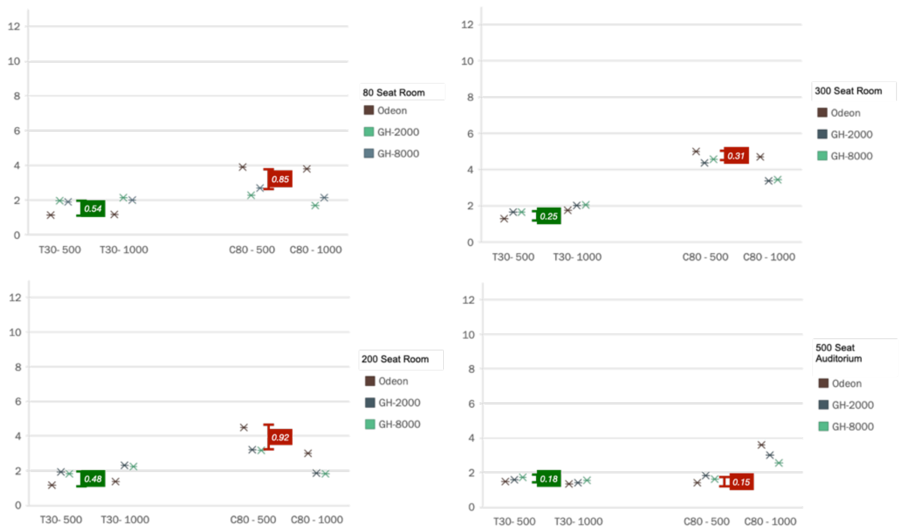

Figure 6. Simulation Results in Comparison

Linked with modeling tools such as Revit and Rhino-Grasshopper 3D enables the system to conduct real-time analysis and calculations. This functionality assists designers and users in promptly comprehending the consequences of modifications to spatial functionality. Consequently, in the intermediate phase of this study, our focus shifted towards enhancing the accuracy of the simulation. We achieved this by utilizing ODEON, a numerical and metric simulation software, as a reference benchmark. The spatial models generated through various modeling tools, including Revit, ArchiCAD 25, Rhinoceros 3D, and SketchUp, served as the basis for our examination of the impacts and disparities in the simulation operations introduced by different modeling systems.

5.1. CONCLUSIONS

This paper introduces a parametric approach to room acoustics simulation using Rhino-Grasshopper allowing interactive modeling and real-time acoustic analysis through ray tracing methods. The parametric workflow allows rapid acoustic analysis during early design stages. The Image Source Method (ISM) and Early Scattered Method (ESM) are used for ray particle tracking. Various modeling tools like Revit, ArchiCAD, Rhino, and SketchUp are used to create spatial models. The paper demonstrates a parametric methodology for interactive room acoustics simulation and analysis. It optimizes the building design process by integrating performance simulation. The parametric workflow may assist participants in getting closing comments in the very early stage of the SD phase.

In the current non-linear workflow of architectural design and construction, this research tool can intervene and streamline the design process and work stages. Through the optimization of the cross-interface/system data modeling shown in Figure 7.

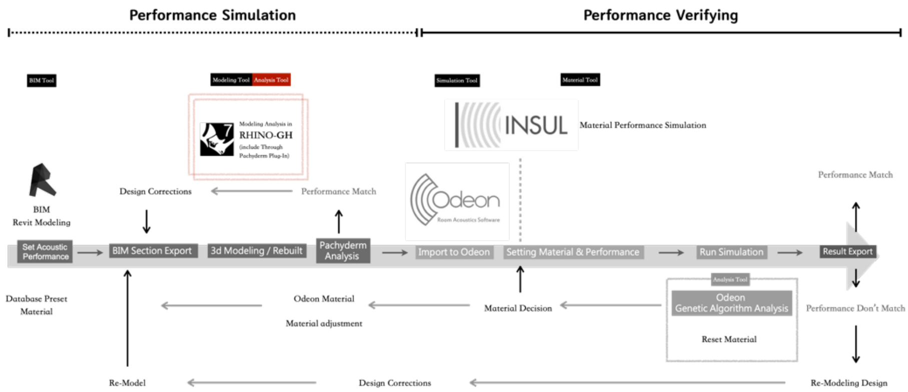

Figure 7. Acoustic Simulation Workflow

Integration coupled with suitable corrections and fine-tuning, it becomes feasible to achieve data results that closely align with those of benchmark simulation software.

The indoor acoustic design/simulation workflow is structured as a bidirectional process involving parametric design and metrics software. This design aims to reduce simulation time and enhance the effectiveness of each tool in the simulation process. For room modeling and research, a singular omnidirectional sound source from ODEON simulation software is employed to simulate and assess the teaching environment. The workflow, impacts, and data acquisition are analyzed. Additionally, the teaching environment is simulated with multiple lines of fire. The following are the conclusions and recommendations derived from this research.

Reverberation time and clarity index (C80) are simulated and compared between tools. The other parametric like IACC and LF which are related to the spatial factors may be discussed for the next stage.

5.1.1. Achievements

- Within the study, sound undergoes multiple reflections within the modeled sandwich thickness. However, in the real environment, the discrepancy arises from the fact that the reflection coefficient of sound traversing through the material doesn't align with the diffusion coefficient of sound absorption.
- The layer-based material setup proves more advantageous for calculating area and specifying materials. Consequently, not all models can be directly imported; some require fine-tuning post-import.
- Number of emission lines in Rhino-Grasshopper, it's observed that 2000 line of rays is closer to the ODEON's performance than 8000 line of rays, with the standard difference of the closest value being 0.04.
- Constructing models with seating, reflective panels, and other objects using linear modeling as opposed to surface structures such as BREP or Mesh files can further reduce the standard deviation of residence numbers, thereby enhancing the accuracy of simulation values.

5.1.2. Limitations and Future Works

- In the BIM workflow, exporting the model in CAD format (.dwg) provides easier analysis than other formats, ensuring more accurate calculations through the logic of linear modeling.
- Given correct modeling, indoor acoustic analysis values can be rapidly obtained, saving significant time in workflow execution. This flexibility allows operators to make corrections compared to software such as ODEON.
- The study employs a single omnidirectional sound source for simulation, without the addition of an electroacoustic system or directional sound source.
- Settings and fine-tuning: In configuration and refinement, this study delves into critical aspects, notably, the calibration of ray numbers, with the ongoing inquiry into whether restricting rebounds to five instances might be overly conservative. Moreover, the incorporation of multiple sound sources is indispensable for a nuanced and comprehensive examination, where both performance and source diversity are pivotal considerations. Additionally, advancements in input/output mechanisms and settings not only contribute to the sophistication of testing environments but also underscore a commitment to refining experimental precision and methodology.
- Calculation optimization: Our research initiates an extensive examination across diverse modeling platforms, emphasizing the need to align these platforms under more analogous conditions. This entails meticulous fine-tuning of file import and transcoding settings. Simultaneously, to enhance the linearity of our simulation methodology, dedicated efforts are directed toward refining Grasshopper-Rhino-based plug-in tools. The intricate comparison between on-site and scaled model results serves as a pivotal focus, representing a significant stride in our ongoing academic research endeavors. This approach not only contributes to the robustness

of our simulations but also holds implications for the broader field of [insert relevant field] by establishing a foundation for more standardized and comparable modeling practices.

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