DOI: 10.61782/fa.2025.0143

FORUM ACUSTICUM
EURONOISE 2025

APPLICATION OF ROOM ACOUSTICS SIMULATION SOFTWARE IN UNIVERSITY TEACHING

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ABSTRACT

Room acoustics simulation software has become an established tool for researchers and consultants. Although such software applications are often regarded as expert tools, they can be effectively integrated into university courses focused on room acoustics and simulation techniques. At RWTH Aachen University, the RAVEN software environment — a C++-based simulation that utilises a hybrid approach that combines the image source model with an efficient ray tracing algorithm — was initiated over 15 years ago. Today, RAVEN is employed in various teaching and research activities and features multiple interfaces, including a MATLAB interface that enables script-based configuration of simulations. Its integration with the 3D modelling software SketchUp creates an interactive environment where students can immediately experience the effects of changes to room designs. This interface allows students to quickly access their first room simulation and auralization, facilitating the incorporation of the software into courses. Currently, it is used in block courses, laboratory sessions, and as a demonstration tool during lectures — not only in Aachen but also at several other universities worldwide. This work summarizes the challenges and opportunities associated with the application of RAVEN in an educational context.

Keywords: *room acoustics, education, simulation, auralization, teaching*

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1. INTRODUCTION

As nowadays, most people spend the majority of their time indoors, room acoustics is of particular relevance in many locations, e.g., in classrooms, in workplace environments or in restaurants. For this reason, the traditional field of room acoustics is even today a part of almost every lecture series related to acoustics. It is popular as it contains concepts which are rather easy to grasp (such as specular reflections or the reverberation time), phenomena which are well-defined and understood such as rooms modes, but also less intuitive and more complex aspects such as the spatial perception of sound in rooms or the description of diffuse sound fields, which are also the topic of current research.

In typical environments we experience in our daily lives, the room acoustics can vary substantially. For the sole purpose of demonstrating the role of absorption, volume and reverberation time, the use of simulations and the tool of auralization in the context of acoustics courses is an effective approach to teach students about room acoustics.

While many (commercial) tools for room acoustic modelling exist since the 1990s [1], many of these tools are (understandably) designed for use by experts and do not have interfaces that allow them to be quickly learned and used in courses. This work introduces the room acoustic simulation software RAVEN [2] and how it is applied in university teaching.

2. THE SOFTWARE ENVIRONMENT RAVEN

The RAVEN (Room Acoustics for Virtual ENvironments) software modules were originally initiated by the Institute of Technical Acoustics at RWTH Aachen University by Dirk Schröder and supervised by Michael Vorländer around the year 2005. The main simulation concept

is based on a hybrid model including the image source model for the specular reflections and a ray tracing algorithm for the diffuse and later part of the room impulse responses. The ray tracing algorithm is extended by a diffuse rain model efficiently determining the amount of scattered energy projected to the receiver. The underlying models have already been developed and elaborated in earlier research projects, successively by Vorländer and Heinz under guidance by Heinrich Kuttruff [3–6] and by Schmitz under guidance of Michael Vorländer [7]. The most comprehensive documentation of the main software library is included in Dirk Schröder's PhD thesis [8].
After its initial phase, in which the base functionality for a GA-based room simulation was implemented, the software was extended with various interfaces and integrated in (VR) applications [9, 10]. The efficient implementation of the room simulation and the synthesis of binaural room impulse responses makes it possible to render auralizations in real-time. A MATLAB interface allows script-based configuration and operation of simulations, making it a convenient tool for researchers - a Python-based interface is currently in preparation. At the moment, the software is not an open-source project, but freely available for academic, non-commercial purposes.

2.1 The SketchUp interface

A plug-in for the 3D modelling software *SketchUp* was created with the intention of providing an easy-to-learn user interface to control a room acoustic simulation and efficiently modify the simulated scene (positions, geometry, boundary conditions). The plug-in's interface, integrated into the *SketchUp* environment, is shown in Fig. 1. By transferring all acoustically relevant information from SketchUp to a C++ application, running in the background, room acoustic parameters and reflection paths can be efficient visualised [11] while the user is able to modify the scene within *SketchUp*. Additionally, room impulse responses for defined positions can be exported, or directly applied for auralizations, either for the static situation, or interactively while the receiver position is moving or the scene is modified [12].
This interface, supported by a basic documentation and a tutorial, makes the RAVEN software suitable for application in university courses, also by students without a background in computer science, engineering or acoustics.

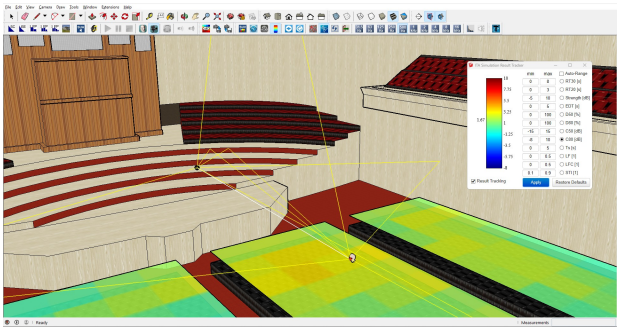

Figure 1. *SketchUp* interface of RAVEN - a simulated concert hall with visualized room acoustic parameters (here: C80) and first order reflection paths.

2.2 Tutorials and examples

Both, for MATLAB as well as for the SketchUp interface of RAVEN, tutorial procedures have been created in English language. The MATLAB tutorial, which is provided in the software's documentation folder, is complemented by various example scripts in the git-repository of the ITA-Toolbox [13] (www.ita-toolbox.org). As the MATLAB interface is mainly intended for researchers, who can be considered as expert users and who typically spend a longer period of time working with the software, the MATLAB interface is rarely used in courses, but frequently applied as a tool in final thesis projects (inside and outside of RWTH Aachen University).
The tutorial document [14] for the SketchUp interface currently includes 17 sections, starting with general information on the involved tools and a very brief introduction of 3D modelling in SketchUp. The main part of the tutorial explains the required steps to start, control a evaluate simulations and auralizations. Completing the tutorial takes around 45 to 120 minutes, depending on the previous experience of the user with SketchUp and room acoustics simulation. The steps of the tutorial also have been recorded and published on *YouTube* [15]. RAVEN's SketchUp tutorial is complemented by a short exercise, which includes the task to run and adjust a simulation of a typical concert hall.

3. APPLICATION IN UNIVERSITY COURSES

Today, RAVEN is used in academic courses related to room acoustics, virtual acoustics and/or auralization at various universities. In these courses, the contents related

to the application of RAVEN range from just demonstrating room simulations and auralizations (by following the tutorial), to specific exercise tasks and project-style group assignments, e.g., the design of a concert hall, theatre or a rehearsal space.

3.1 RAVEN at RWTH Aachen University

For a period of around 10 years, the RAVEN software has regularly been part of two courses at the Institute for Hearing Technology and Acoustics. The first one is a laboratory course on *Acoustic Virtual Reality*, where each semester eight students from electrical engineering learn about the concepts of room acoustic and corresponding geometrical acoustics-based simulation and auralizations. As part of one out of eight experimental session of the course, the students first have to investigate the difference between RAVEN's hybrid simulation model to a previously implemented simplified image-source model [16], before they are asked to investigate the stochastic error of the simulation and its dependence on the number of ray tracing particles. In a final step, the students have to check the impact of an occupied seating area in contrast to an empty concert hall.
The second teaching activity is a one-week block course on room acoustics, which is attended by 30-40 students from architecture, electrical engineering and sound engineering. In this course, students learn about the fundamentals on room acoustics, related regulations as well as measurement and simulation techniques until on the third day. Afterwards they form (if possible) interdisciplinary project groups to design (performance) spaces, where room acoustics are of critical relevance. The project scenarios are usually adapted examples from past editions of the ASA student design competition (Newman Student Award Fund). During the block course, the students are provided with the RAVEN software and can use it to design and improve the acoustics of the designed venue. The application of RAVEN for their projects is complemented by other tools such as equation-based approaches (implemented in spreadsheets) or by web-based applications (e.g., the *amray* Raytracing Sketchpad [17]) which can easily be accessed by the students, supporting their design decisions.
In addition to these courses, the software has also been applied at RWTH Aachen University in seminar work of architecture and electrical engineering students, as a demonstration tool in lectures and laboratory tours, and in numerous final thesis projects (BSc & MSc).

3.2 RAVEN used by other universities

In recent years, RAVEN has been also integrated in or been part of courses in Australia (the University of Sydney), in the UK (University of Edinburgh), in Spain (Universitat Politècnica de Catalunya) and on a regular basis at the Slovak University of Technology in Bratislava. At TU Berlin, HS Düsseldorf and HfM Detmold (all in Germany), the software is also frequently applied in final thesis projects. During the EAA Summer School 2023 (part of Forum Acusticum 2023 in Turino, Italy), the software was integrated in the course on Auralization.
At the Slovak University of Technology in Bratislava, RAVEN is used as a tool in a yearly course for around 15 students from architecture and civil engineering - these students work in larger groups with the task to design rooms in various types of buildings such as music schools, primary schools, university buildings and concert halls. Rooms of these buildings are evaluated with respect to room acoustic parameters required in the corresponding standards and recommendations, and compared to good practice example projects. In some cases, students with a focus on building services or building technology are asked to conduct a parametric study (working in smaller groups) to investigate the influence of various factors on room acoustic parameters, e.g., the influence of volume vs. average sound absorption coefficient and shape, etc.

4. SUMMARY

This work introduced the room acoustic simulation software RAVEN and summarized how it is applied in teaching activities. In general, it is a challenge to implement software, which is not only intended as a research tool, but can also be used in teaching, not only as a tool to demonstrate and explain room acoustics (and its simulation), but also during hands-on exercises in which the students can learn how to run room simulations in a short amount of time and directly use for short studies and projects.
When teaching courses that involve the use of the software, it is essential to ensure that despite a quick and rather short introduction to the software, the students learn how to use the simulation correctly. They need to be made aware of uncertainties, the limits of the simulations and possible errors in the simulation results.
After years of application, based on positive experiences and feedback, the additional effort for specifically creating interfaces and documentation can be considered as worthwhile. However, similarly to other software solutions that

have been in use for many years, the frequently changing staff at the university and dependencies on third party software packages and operating systems are challenges that need to be tackled on an ongoing basis to ensure that the software can continue to be used in teaching.

5. ACKNOWLEDGMENTS

The authors would like thank the developers of RAVEN, especially Dirk Schröder, Sönke Pelzer and Ralf Schallenberg for remarkable efforts during the implementation of the main parts of the RAVEN software and the SketchUp interface. Thanks also to Vojtech Chmelík from the Slovak University of Technology in Bratislava for providing details on the usage of RAVEN in their courses.

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