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A systematic review for acoustic room simulation

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ABSTRACT

This paper gives an overview of the current state-of-the-art numerical techniques used to predict the acoustic behavior of reverberant environments. Establishing criterion for inclusion and exclusion of works and applying a systematic mapping protocol, we obtained a set of classes that allowed to catalog, identify and classify the technical types used according to the type of environment analyzed. Results show quantitatively the bibliographic cataloging, the totalization of the acoustic simulation tools, the numerical methods; acoustic parameters addressed by the tools, the databases where the works were published, as well as the evolution of the publications in recent years. The data obtained allow us to take a look at the challenges for future research.

Keywords: Sound Quality, Room Acoustics, Simulation Tools
I-INCE Classification of Subject Number: 76 Modeling, prediction and simulation

1. INTRODUCTION

The procedures about reverberation for the evaluation of the acoustic quality of rooms can be classified in: analytical models, method of scales and numerical methods. Difficulties about presenting details of sound propagation in complex geometries presents

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as main limitation of the analytical method. When high-scale models allow larger amounts of financial resources when it comes to compare to the previous model, they still have to pay the high financial cost and time to generate models of resource for each situation. The use of the computer to predict acoustic room quality has been increasingly frequent among architects and acoustic designers [1]
Regarding this, the numerical techniques for an acoustic modeling were analyzed and tested with an approximate purpose of the simulated results of the experimental ones [1]. Regarding the computational tools, it is possible that the technological of the last generation, launched the process of comparison, that different variants for a solution, such as statistical, geometric and condition-based, as presented by [2] [3], [4], [5].
Due to the diversity of computational systems the ability to estimate sound behavior, the increase of the following guiding problem: "What state of the art of programs that can be improved in the sound behavior of reverberant environments?" This work aims to make a systematic mapping of classroom acoustic design tools to support the future development of new algorithms for acoustic simulations

2. METHOD

In order to conduct this work, the MS protocol, proposed by [6], was defined and followed, which presents a structured search and classification of published works in specialized vehicles. The objective is to provide an overview that will be obtained from guiding questions, elaborated by the authors of the study. To do so, a set of steps are presented in the flowchart shown in Figure 1.

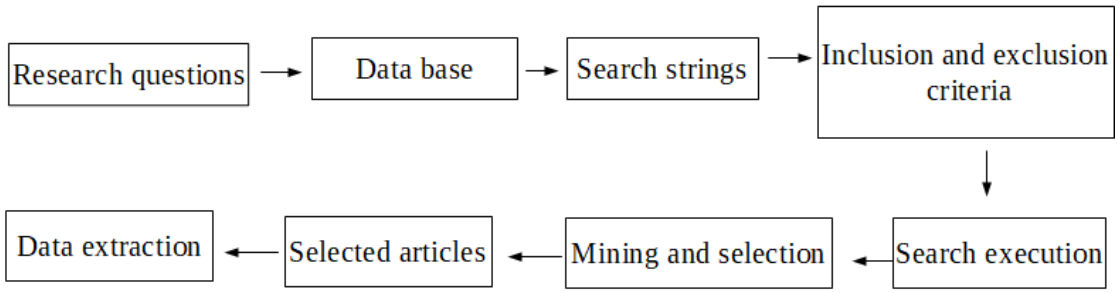

Figure 1: Stages of Systematic Mapping

3. PROTOCOL OF SYSTEMATIC MAPPING

In this section, the MS steps followed for this work will be detailed.

3.1. Search Issues

- Q1: Which tools are available and how many scientific publications are related to each tool?
- Q2: Which are the numerical methods used and how many scientific publications are related to each of these methods?
- Q3: Which are the acoustic quality parameters that are addressed in the methods identified in Q2, and what are the scientific publications related to these properties?
- Q4: Which are the basic characteristics of the tools found? In this question we intend to address some characteristics of the tools, such as their technology (software, algorithm, prototype), date of development, who produced, versions.

3.2. Databases and Search String:

Databases: IEEE (Institute of Electrical and Electronics Engineers) Xplore Digital Library, Elsevier ScienceDirect and Google Scholar. In addition to periodical publications and events supported by specialized entities such as SOBRAC (Brazilian Society of Acoustics) and SPA (Portuguese Society of Acoustics).

3.3 - Search Strings

The search strings were generated from the keywords, combining them even with the use of logical operators OR (OR) and AND (E). Table 1 shows the keywords and strings adopted in the conduction about this research.

Language	Key words	Strings
Portuguese	Simulação, Sala, Acústica, Software, Algoritmo, Modelagem	"Software AND acústica AND sala" OR "Simulação AND acústica AND sala" OR "Modelagem AND acústica AND sala" OR "Algoritmo AND acústica AND sala"
English	Room Acoustics Software, Software, Algorithm, Acoustics Simulation	"Room Acoustics AND Software" OR "Room Acoustics AND Algorithm"

Table 1: Key words and strings adopted, in English and Portuguese

3.4 - Inclusion and Exclusion Criteria

Table 2 lists the Inclusion Criteria (CI) and Exclusion Criteria (CE) adopted by the protocol of action.

Inclusion Criteria		Exclusion Criteria	
ID	Description	ID	Description
CI 1	The period of its publication should be between the years of 2000 and 2016.	CE1	Papers published between the years 2000 and 2016
CI2	The work is written in English or Portuguese.	CE2	The work is written in a language other than English or Portuguese.
CI3	The work whose full version is available on the web .	CE3	The full version of the paper is not available on the web.
CI4	The work should be about use, implementation or just mention acoustic simulation tools.	CE4	Work that does not address the use, implementation and even mention the acoustic simulation tools.

		CE5	The work be duplicated. (More than one file of the same paper)

Table 2: Criteria for inclusion and exclusion of works

3.5 - Search Execution

The inclusion and exclusion criteria, were applied during the research, such as the period and the language. However, to apply other IC and / or CE the searches were performed manually. At this point it is important to mention that there was a large number of works, making manual search impossible. Given this scenario, the Google Scholar search engine has been configured to filter only Portuguese-language works. The other databases continued to search for works in English and Portuguese, and limited to the works published on those platforms.

At the end of this stage, 675 papers were identified. 3.6 - Mining and Selection As can be seen in the previous section, there has been a brief selection of works still during the search. After a more rigorous mining, applying the IC and EC, in the previously selected works, the total of 675 jobs were reduced to 114 works, for instance, the application of CE3 and CE5. In sequence, we analyzed the title, keywords and the abstract of the works, verifying if they are approach the thematic of tools of simulation and acoustics of closed environments. The conclusion of this stage resulted in selected papers to solve the questions of this research.

3.7 - Selected articles

This stage consists of the set of works found during the execution of activities 1 to 5 of the research protocol. At the end of the fifth stage, 49 papers were selected for the remaining stages.

3.8 - Extraction of data

The data extraction were based only on the analysis of the summary of the selected works, in order to verify whether there is an overview of the work containing a contextualization of the problem and it is possible to verify whether the research only uses and / or proposes a simulation tool acoustics. However, in cases of doubt, the methodology, the theoretical reference and the results in the search for information about these tools were also verified.

4. RESULTS AND DISCUSSION

4.1 Acoustic simulation tools

Table 3 shows the acoustic simulation tools found and the number of publications related to them. Algorithms, commercial software and free software totaling a total of 20 tools. It is noticeable the diversity of tools found within the limits adopted in this research. Also notable is the unevenness of the citations in relation to the tools. Also notable is the difference in the citations in relation to the tools, that most of the quotations were concentrated in two software with 22 and 11 citations. At the end, it was a total of 61 citations referring to the acoustic simulation tools.

ID	Tools	Citations
1	Odeon	22
2	CATT Acoustic	11
3	EASE	6
4	Epidure	2
5	RAIOS	2
6	Ramset	2
7	RAVEN	2
8	Raynoise	2
9	Algorithm 1	1
10	Algorithm 2	1
11	Algorithm 3	1
12	Algorithm 4	1
13	CadnaR	1
14	DIVA	1
15	EARS Auralization	1
16	ESP-r	1
17	SOFE	1
18	Software 1	1
19	Software 2	1
20	Virtusound	1
Total	20 Tools	61

Table 3 - Acoustic simulation tools

4.2 Acoustic simulation methods

Table 4 shows the data obtained in the search that answers the question (Q2: What are the numerical methods used and how many scientific publications are related to each of these methods?). This table contains the number of publications related to the numerical methods cited in the works. Although the literature provides a series of numerical models with different approaches, the present research is restricted only to the models based on the geometric model Thus, a total of 8 types of numerical methods were identified. As shown in the table Hibrido (Image Sources and Lightning Trace) is the one with the most citation, a total of 22 citations; then the Radius Tracing with 16 citations; o Source Image with 5 citations; The Hybrid method (Lightning Tracing and Energy Transition) with 2 citations; and the methods (Beam Rays, Triangle Rays, Hybrid (Source Image and Hierarchical Radiance), hybrid (Image Source and Stochastic Rays) each with only 1 (one) citation. Another point that is noticeable in this table, it is that 50% of the methods are hybrids, that is, a combination of two methods. It is also possible to identify that the Image Source method is present in 50% of the methods found.

Table 4 - Number of citations and numerical methods found

Citations	Numbers methods
1	Method of Tapered Rays
	Triangle Rays Method
1	Hybrid (Image Source and Hierarchical Radiosity)
1	Hybrid (Image Source and Stochastic Ray Tracing)
2	Hybrid (Lightning Tracing and Energy Transition)
5	Image Source
16	Lightning Tracing
22	Hybrid (Image Sources and Lightning Tracing)

Table 4 - Number of citations and numerical methods found

The Table 5, presents the results that answer the question (Q3: What are the properties of acoustics that are addressed in the methods identified in Q2, and what are the scientific publications related to these properties?). Each method is able to implement functions that analyze different parameters of acoustic quality, being that in Table 4 it contains the methods found and their respective acoustic parameters.

Table 5 - Relationship between simulation methods and acoustic parameters

Acoustics Parameters	[1]	[2]	[3]	[4]	[5]
RT	x	x	X	x	X
EDT		x	X	x	X
D50		x	X	x	X
C80		x	X	x	X
Ts		x	X	x	X
LF		x	X	x	X
LFC		x		x	X
IACC		x		x	X
Rasti		x	X		
STI		x	X		
G		x	X		
BR		x	X		

Table 5 - Relationship between simulation methods and acoustic parameters

Description: [1] Image source; [2] Ray tracing; [3] Hybrid Method (Image Source and Lightning Tracing); [4] Hybrid method (ray tracing and energy transition); [5] Source image and hierarchical radiosity.

As shown in Table 5, it was possible to identify the acoustic parameters of only 5 numerical methods. The presence of the Reverberation (TR) parameter in all methods is remarkable. It is also noticeable the number of parameters implemented in the Hybrid methods (Image Source and Lightning Trace) and Lightning Trace. Some papers found, presented only a few acoustic parameters, since they intended to analyze these specific parameters. In cases where the work only referred to or implemented a tool, it also mentioned only the desired parameters, making it not always possible to identify all the parameters.

The aim of this work was to search for digital tools of various acoustic analysis technologies (software, algorithm, prototype, etc.). Only two types of technologies were found: Softwares and Algorithms. In the works you find it was not always possible to identify if the tools are free or commercial.

Another aspect refers to the authorship of the tools, which can be seen in Table 6. Only 9 papers describing works that report the authorship of the tools have been identified. For the construction of the frame were related the technology of the tool and their respective authors. In summary, 3 papers related to algorithms, each one created by the authors of the works (works), 2 works that deal with software, were also created by the authors themselves, and lastly, 4 papers that report on software that were developed by third parties.

How many	Type Authors	Type Authors
3	Algorithms Own	Algorithms Own
2	Softwares	Softwares
1	Software Institute of Technical Acoustics at RWTH Aachen University	Software Institute of Technical Acoustics at RWTH Aachen University
1	Software Group of Acoustics and Noise Control of CAPS - Instituto Superior Técnico de Lisboa	Software Group of Acoustics and Noise Control of CAPS - Instituto Superior Técnico de Lisboa
1	Software Physikalisch-Technischen Bundesanstalt - Germany	Software Physikalisch-Technischen Bundesanstalt - Germany
1	Software Company Acoustic Design Ahnert - Germany	Software Company Acoustic Design Ahnert - Germany

Table 6 - Authorship of acoustic simulation tools

4.3 Threats to MS validity

Although this MS was planned and conducted according to the protocol defined above, there are still threats to validity in the presented results. Due to the inclusion and exclusion criteria, the set of primary studies related to room acoustics modeling was limited to the period between 2000 and 2016, which does not correspond to the set actually existing in the literature.

4.4 Case Study - Conrado Silva Acoustic Competition

Considering the need to diffuse the importance of the acoustic design of buildings in the training of Brazilian architects and engineers, the Brazilian Society of Acoustics (SOBRAC) promoted in 2018 the 1st Student Concurso de Acústica Conrado Silva. Thus, the competition was aimed at teams of undergraduate students from all over Brazil, enrolled in the courses of architecture and urbanism, acoustic engineering, civil engineering, electrical engineering, mechanical engineering, physics and other courses that have the acoustics of rooms as a area of professional knowledge.

Recognizing the new technologies available for acoustic simulation of rooms, but considering the degree of still restricted access of these tools in undergraduate courses in engineering and architecture in Brazil, the competition listed two categories of project, called analog and digital. In this last category, the acoustic project developed should be accompanied by sound samples, in order to reproduce the auditory experience of the conceived room.

Of the twelve works that competed for the awards (Table 7), four were of the digital category. In the analog category, of the eight papers submitted, only two papers used tools and acoustic simulation. Thus, only 50% of the works submitted to the contest used acoustical simulation of rooms. In this sense, the importance of the continuity of initiatives such as this competition as a strategy for the diffusion of knowledge in acoustics in undergraduate courses is highlighted.

Of the four works of the digital category, that is, that presented auralizations, three used commercial packages, being software of Brazilian origin. One team used a tool of authorship of the team, not yet commercial. From the analysis of the relationship between the design category and the presented acoustic parameters, it is observed that the absence of computational tools makes it difficult to evaluate room acoustic quality parameters beyond the reverberation time

Work	**Category**	**Acoustic parameters**	**Softwares**
CS-01	Digital	EDT, T20, T30, D50, C80, Ts	Raios 7
CS-02	Analogic	RT60	Not applicable
CS-03	Analogic	RT60	Not applicable
CS-04	Digital	T30, C50, C80, Ts, MTI, EDT, LEF	Pachyderm Acoustics
CS-05	Analogic	RT60	Not applicable
CS-06	Analogic	T30, EDT, E50, D50, C80	Odeon
CS-07	Digital	SPL, EDT, C80, D50, STI	Odeon
CS-08	Analogic	RT60	Not applicable
CS-09	Analogic	RT60	Not applicable
CS-10	Digital	RT60, EDT, Ts, D50, STI, LEF, Fator de Força, BR	Algorithm
CS-11	Analogic	RT60	Not applicable
CS-12	Analogic	RT60	Ease 4.4

Table 7- Synthesis of the Systematic Mapping of the Acoustical Concurso Silva

5. CONCLUSIONS

The systematic mapping of acoustic simulation tools used in Brazil was based on 49 national papers published between 2000 and 2016. 4 research questions were established to guide this study. The research questions sought to map the acoustic simulation tools, the acoustic parameters used in each of the tools, citations, among others. For this, some criteria were adopted to select the articles that could answer the defined questions.

The main results demonstrate the concentration of two most referenced softwares, with emphasis on the use of hybrid numerical methods, with emphasis on the relation of the acoustic parameters addressed by each method. Another relevant aspect refers to the predominance of using a few predominantly commercial tools presents itself as a challenge to be overcome.

It is important to emphasize that this MS was planned and conducted according to the protocol. Nevertheless, there are threats to validity in the presented results, due to the inclusion and exclusion criteria, after all the group of primary studies related to the modeling of room acoustics, was limited to the period between 2000 and 2016, which does not correspond to the set actually existing in literature.

On the other hand, the First Concurso Silva Acústica Student Competition held in 2018 by the Brazilian Society of Acoustics presented a similar sampling to that carried out in other databases from 2000 to 2016. Thus, the results suggest the representativeness of the contest for the state of the art in acoustic simulation tools in Brazil.

Therefore, there is a need for the development of free software for acoustic simulation of rooms using hybrid methods, such as a possible strategy to popularize acoustic knowledge and increase the acoustic quality of architectural projects.

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