SUPERCOMPUTING FOR ACOUSTIC SIMULATION. A REVIEW

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Abstract
Acoustics plays a significant role in various aspects of everyday life and finds applications in diverse fields such as medicine, where ultrasound is used to detect anomalies in the human body, noise pollution control, music, and the study of the universe, among others. This article explores the extent of scientific literature on supercomputing for acoustic simulation. The methodology consists of four steps: formulating research questions, conducting a literature search, selecting highly impactful articles, and data compilation. Out of a total of 211 articles obtained from reviewed databases, including Springer, Google Scholar, ScienceDirect, Scientific Reports, ChEES, Journal of Physics, Hindawi, and Research Article, 20 articles were chosen for analysis. It was concluded that the dynamic study of sound is indeed complex, requiring intensive data processing. This necessitates the use of supercomputers with multiple cores to solve various mathematical models, with the fundamental focus of the study being the resolution of the wave equation.
***Keywords**: supercomputer, acoustics, simulation, noise, clusters, ultrasound.*

(1) INTRODUCTION

It is now important to analyze the dynamics of sound and its effects. As a result, computer acoustics (CA) has acoustic subfields, which include a combination of numbers and numerical analysis algorithms to approximate the sound field in a model and simulation computer [1].
Unfortunately, the dominant wave equation is often unsuitable for analytical solutions when the spatial distribution of geometrical boundary conditions and fluid material properties is complex [2]. The same is true for wave equations in other areas of physics, such as electromagnetics and optics. In these situations, the numerical resolution of the wave equation can be a powerful tool to calculate the audio quantity of interest. Otherwise, there is no other way to obtain this information [3]. Parallel processing of audio data streams is introduced to shorten the decision-making time in sound event recognition. A supercomputing cluster environment is used with a dedicated framework for real-time multimedia data stream processing [4].
Thanks to this spectacular advance, it is possible to solve or improve existing solutions to problems of acoustics. In the present collection of research articles, emphasis is placed on ultrasound applications, a tomographic scheme completely in 2D and 3D, which is an alternative variant to the inverse problem that is solved for each 2D plane, using acoustic simulation on a supercomputer the object is reconstructed as 3D images. [5]. An important application is the supercomputer pollution assessment, where a systematic methodology is established to compute urban traffic noise maps in complex 3D building environments [6].
This review article has five sections, including the introduction, and is structured as follows: Section 2 presents the methodology followed to select the supercomputing items for acoustic simulation, Section 3 details the literature review and results obtained, and finally, Section 4 details the conclusions.

(2) METHODOLOGY

Before a literature review, the guidelines of the PRIMAS method were followed [7]. The methodology is based on the review of databases freely accessible to the authors, such as the following: Springer, Google Academic, ScienceDirect, Scientific Reports, ChEES, Journal of Physics, Hindawi and Research Article. Then, parameters such as research questions, document search, selected articles and data collection are established, allowing researchers to obtain the most relevant and updated information to generate a high-quality scientific paper.

2.1 Research questions

The number of questions generated for the present research was established according to an analysis of the subject under study, in this case, the study of supercomputing for acoustic simulation. For the execution of this research point, the bibliography recommends considering some points of view, such as acoustic simulation applied to urban mobility, medical applications in tomography and solution to physics problems. Table 1 shows the questions formulated to continue with the analysis of the scientific literature.

Table 1. Research Questions.

Number	Research questions	Motivation
PI1	What is supercomputing?	Identify data processing and simulation capabilities.
PI2	What is the importance of supercomputer simulation of acoustics?	Identify the advantages of dynamic sound analysis.
PI3	What are the advances generated with supercomputing acoustic simulation?	Identify the main applications in daily life.

2.1 Document Search

A bibliographic search was performed without restriction in years since, in the compilation executed, all the information that has been verified and published after many years of study in this new field of supercomputing applied to the resolution of acoustic problems was sought. Considering the points of view described in the previous section, for the first point, the authors filtered the information only from 2020 since it is the most recent and verified in the scientific literature in this field of study. Then, it was filtered by publication relevance, and finally, 20 articles referring to the approach given in the research questions were chosen.

2.2 Selected articles

Table 2 shows the procedure used for selecting and discarding shows the procedure used for the selection and discarding of information obtained from the articles reviewed, for which the parameters based on the Prisma methodology were established, as shown in Figure 1.

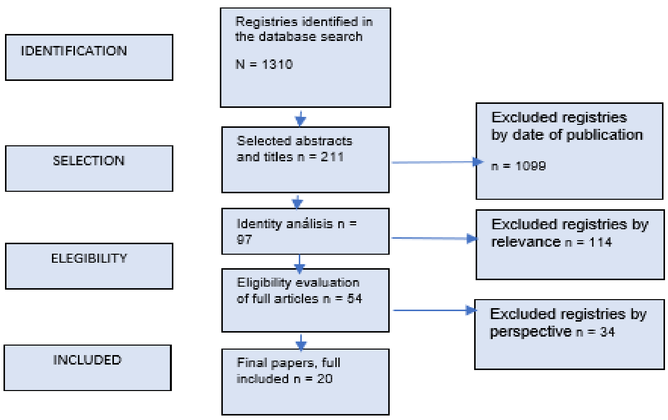

Figure 1. Prisma Methodology Flowchart.

Table 2. Inclusion and exclusion criteria

Number	Inclusion	Exclusion
C1	Articles related to supercomputing.	Thesis
C2	Articles published in the last 5 years.	Articles not related to supercomputing
C3	What are the advances generated with supercomputing acoustic simulation?	Identify the main applications in daily life.
C4	Articles related to supercomputing in acoustic simulation.	Review articles
C5	Articles related to supercomputing applications in acoustic simulation.	Review articles

2.3 Data collection

Finally, after the discretization of the analyzed publications, several aspects have been considered such as: the field of simulation development, supercomputer acoustics, supercomputing advances in acoustic simulation, relevant applications for current problems, among other aspects, to conclude with a selection of 20 articles, which are detailed in Table 3 in chronological order of publication, whose extracted information will be based on the research questions.

Table 3. Data collection.

Code	Title	Database	Year	Point of view	Author(s)	Target
P1	A quantum circuit simulator and its applications on Sunway TaihuLight supercomputer	Scientific reports	2021	VP3	Wang, Z., Chen, Z., Wang, S., Li, W., Gu, Y., Guo, G., & Wei, Z.	Emulating the effect of noise and support more kinds of quantum operations. Second, our simulator is of high efficiency. The simulator is designed in a two-level parallel structure to be implemented efficiently on the distributed many-core Sunway TaihuLight supercomputer.

P2	3D Acoustic-Elastic Simulations for Tsunami-Genesis	ChEESE	2021	VP1	Krenz, L.	Fully coupled elastic-acoustic simulations capture more effects than typical two-step strategies
P3	Solving Complex Acoustic Problems Using High Performance Computations	Springer	2021	VP1	Bazulin, E., Goncharsky, A., & Romanov, S.	Computational Acoustics (CA) has emerged as a subdiscipline of acoustics, concerned with combining mathematical modeling and numerical solution algorithms to approximate acoustic fields with computer-based models and simulation. Using CA, acoustic propagation is mathematically modeled via the wave equation, a continuous partial differential equation that admits wave solutions.
P4	Dynamic noise mapping of road traffic in an urban city	Springer	2021	VP3	Mishra, R. K., Nair, K., Kumar, K., & Shukla, A.	Analyze the spatial distribution of traffic noise levels in the city of Delhi through creating noise maps with the help of GIS.
P5	Simulations in Problems of Ultrasonic Tomographic Testing of Flat	Springer	2020	VP3	Romanov, S.	Presents a computer simulation study on a problem of ultrasonic

	Objects on a Supercomputer					tomographic imaging of welded joints in flat metal objects.
P6	Urban road traffic noise spatiotemporal distribution mapping using multisource data	Science Direct		VP3	Lan, Z., He, C., & Cai, M.	This study proposes a method about urban road traffic noise spatiotemporal distribution mapping to obtain the representative road traffic noise maps of different periods.
P7	Automated reconstruction of 3D input data for noise simulation	Science Direct	2020	VP3	Stoter, J., Peters, R., Commandeur, T., Dukai, B., Kumar, K., & Ledoux, H.	This paper presents a methodology to automatically generate 3D input data as required in noise simulations (i.e., buildings, terrain, land coverage, bridges, and noise barriers) from current 2D topographic data and point clouds. The generated data can directly be used in existing noise simulation software.
P8	Evaluation of urban traffic noise pollution based on noise maps	Science Direct	2020	VP3	Yang, W., He, J., He, C., & Cai, M.	Evaluate the traffic noise pollution based on noise maps. Twenty-four-hour noise maps of the Chancheng District in

						Foshan, China were developed for this study, and the results analyzed. The study area is divided into four types, based on the land use requirements for the acoustic environment, and the calculated noise value is compared to the noise limits of each class of the area.
P9	Supercomputer Simulations of Ultrasound Tomography Problems of Flat Objects	Springer	2020	VP3	Romanov, S. Y.	Investigating the capabilities of wave tomography methods via supercomputer numerical simulations on a model problem of imaging the wave velocity structure inside flat solid objects.
P10	Supercomputer Simulations in Development of 3D Ultrasonic Tomography Devices	Springer	2020	VP3	Goncharsky, A., & Seryozhnikov, S.	Determine the optimal characteristics of ultrasound tomographic scanners for differential breast cancer diagnosis. Numerical simulations of various tomographic schemes were performed on a supercomputer. In this scheme, the inverse

						problem is solved for each 2D plane separately. A fully 3D tomographic scheme is an alternative variant, in which the acoustic properties of the object are reconstructed as 3D images.
P11	Solving Inverse Problems of Ultrasound Tomography in a Nondestructive Testing on a Supercomputer	Springer	2019	VP3	Filatova, V., Danilin, A., Nosikova, V., & Pestov, L.	This paper is concerned with the use of a supercomputer to solve tomographic inverse problems of ultrasonic nondestructive testing in the framework of a scalar wave model.
P12	the vortex wake behind a wing in the supersonic flow	Journal of physics	2019	VP2	Borisov, V. E., Konstantinovskaya, T. V., Davydov, A. A., Lutsky, A. E., Shevchenko, A. M., & Shmakov, A. S.	In this paper an investigation of an acoustic type waves influences on a wingtip vortex wake parameters were performed in a supersonic flow. Numerical simulations were carried out at the Keldysh Institute of Applied Mathematics RAS using the parallel algorithm for

						turbulent flow simulation.
P13	Supercomputer Simulations of the Medical Ultrasound Tomography Problem	Springer	2019	VP3	Filatova, V., Danilin, A., Nosikova, V., & Pestov, L.	The inverse problem of medical ultrasound tomography consists in finding small inclusions in the breast tissue by boundary measurements of acoustic waves generated by sources located on the boundary. The numerical solution of the direct and inverse problems relies on standard parallel computing libraries (MPI and OpenMP) and is carried out on a cluster system.
P14	Urban Traffic Noise Maps under 3D Complex Building Environments on a Supercomputer	Hindawi	2018	VP3	Cai, M., Yao, Y., & Wang, H.	To solve the problem of computing complexity, a systematic methodology for computing urban traffic noise maps under 3D complex building environments is presented on a supercomputer.
P15	Supercomputer Simulation Study of the Convergence of Iterative	Springer	2018	VP3	Romanov, S.	This paper is dedicated to developing effective methods of 3D

	Methods for Solving Inverse Problems of 3D Acoustic Tomography with the Data on a Cylindrical Surface					acoustic tomography. The inverse problem of acoustic tomography is formulated as a coefficient inverse problem for a hyperbolic equation where the speed of sound and the absorption factor in three-dimensional space are unknown. The developed algorithms can be efficiently parallelized using GPU clusters. Computer simulations show that a GPU cluster can perform 3D image reconstruction within a reasonable time.
P16	A framework for 3D traffic noise mapping using data from BIM and GIS integration	Taylor & Francis	2016	VP3	Deng, Y., Cheng, J. C., & Anumba, C.	Traffic noise is a major health concern for people living in urban environments. Noise mapping can help evaluate the noise level for certain areas in a city. Traditionally, noise mapping is performed in 2D geographic information

						system (GIS). 3D GIS is also emerging in noise mapping in recent years.
P17	created with use of supercomputing grid	Research Article	2014	VP3	Szczodrak, M., Czyzewski, A., Kotus, J., & Kostek, B.	The services described in this document address two issues, the first is related to noise mapping, while the second focuses on the evaluation of noise dose and its influence on the human auditory system. The services discussed were developed unexpectedly within the PL-Grid Plus Infrastructure accumulated by the Polish academic supercomputing centers.
P18	Acceleration of decision-making in sound event recognition employing supercomputing cluster	Science Direct	2014	VP2	Lopatka, K., & Czyzewski, A.	Parallel processing of audio data streams is introduced to shorten the decision-making time in hazardous sound event recognition. A supercomputing cluster environment with a framework dedicated to processing multimedia

						data streams in real time is used.
P19	Employing Supercomputing Cluster to Acoustic Noise Map Creation	AES E-LIBRARY	2012	VP3	Czyzewski, A., Kotus, J., Szczodrak, M., & Kostek, B.	Determining acoustic noise distribution and assessing its adverse effects in short periods inside large urban areas owing to the employment of a supercomputing cluster.
P20	Software for calculation of noise maps implemented on a supercomputer	Springer	2009	VP2	Czyżewski, A. N. D. R. R. Z. E. J., & Szczodrak, M. A. A. C. C. I. E. J.	The aim of implementing the algorithms on a computer cluster is explained. Selected implementation details of the software called Noise Propagation Model are described. The software interaction with the data acquisition system is presented. Finally, noise maps obtained using the described software are presented.

(3) RESULTS

The following is a summary of the selected papers, which have been considered comprehensively, based on the points of view mentioned in Section 2.1.

3.1. Supercomputing Simulation

From the study of acoustic simulation by supercomputing, the most prominent approaches have been obtained within the VP1 point of view described below:

Bunting **[1]** refers that the dominant wave equation is generally not useful for analytical solutions when the geometric boundary conditions and the specific spatial distribution of the material properties of the fluid are complex. In these situations, the root of the wave equation is a powerful tool to calculate the sound of interest. Otherwise, there is no other way to obtain this information. In addition, Wang and Chen **[6]** state that the classical simulation of quantum computing is vital for verifying quantum devices and evaluating quantum algorithms, and Krenz **[2]** clarifies that numerical methods in computational acoustics focus on taking the continuous equations of calculus and converting them into discrete linear algebraic calculations, which can be solved on digital computers. The most general methods include the finite difference method, the finite volume method, the spectral element method, the limiting element method, and the finite element method. However, eh numerical strategy for solving acoustic equations has its niche applications,trengths/weaknesses, and applications for modern high-performance computing **[1]**.

3.2 Acoustic simulation by supercomputing.

The importance of acoustic simulation by supercomputing lies in the solution of the complex wave equation, as well as predicting its behavior in each time, with a large amount of data being processed. It is for this reason that the point of view for its analysis (VP2) has been considered and is described below:

Szczodrak, M., Czyzewski, A. **[4]**, **[8]** They apply parallel processing of audio data streams and supercomputers with a dedicated framework to process multimedia data streams in real-time to reduce the decision-making time for recognizing audio events. The audio event recognition algorithm is used based on foreground event detection, calculation of their properties and event classification in a short time, suggesting different strategies to improve the decision-making time.

Wang and Chen **[3]** present a new quantum circuit simulator developed on the Sunway TaihuLight supercomputer. The simulator consists of three mutually independent parts to calculate a quantum state's total, partial and single amplitudes with different methods. It can emulate the F. Bastidas and C. Cepeda noise effect and support more types of quantum operations. The random quantum circuits can be simulated with 40, 75 and 200 qubits in the total, partial and single amplitude, respectively.

3.3 Important applications of Supercomputing Acoustic Simulation.

Fundamentally, this section has tried to focus on two main applications: The first one is oriented to ultrasound equipment used in the study of materials and medicine through tomographies to detect anomalies in our body. The second application deals with the analysis of noise pollution in urban mobility. Below, some research work is described on these important topics.

3.3.1 Acoustic Simulations applied to Ultrasonic Devices for objective evaluation.

Goncharsky and Seryozhnikov **[5]** represent an improvement over current tomography methods in which the inverse problem is solved individually for each 2D plane, and 2D images are obtained. An alternative variant is to reconstruct.

Romanov **[9]** on the contrary, compares the results of problem-solving with complete and incomplete data sets. The proposed scalable digital algorithm can be efficiently parallelized on supercomputers. The calculations were performed on 50 CPU cores of the "Lomonosov-2" supercomputer at Lomonosov Moscow State University. Numerical simulations of different tomography methods were performed using a high-performance algorithm and supercomputer software developed in this study. The acoustic and geometrical parameters of the simulation correspond to the real test of nondestructive testing of solids.

Bazulin et al. **[10]**, **[9]** **[11]** developed an experimental confirmation of the adequacy of the underlying mathematical model. Furthermore, the proposed scalable numerical algorithms can be efficiently parallelized in the calculations performed on 384 computing CPU cores of the supercomputer "Lomonosov-2" at Lomonosov Moscow State University.

Romanov **[12]** presents the development of effective methods of 3D acoustic tomography. The inverse problem of coefficients for a hyperbolic equation of acoustic tomography, where the speed of sound and the absorption factor in 3D space is unknown. An easy-to-implement 3D tomographic scheme with the specified data on a cylindrical surface is used in the model problem. The developed algorithms can be efficiently parallelized using GPU clusters. Computer simulations show that a cluster of GPUs can perform 3D image reconstruction in a reasonable time.

3.3.2 Acoustic simulations for ultrasound devices applied to medicine.

Goncharsky & Seryozhnikov **[5]** determined the optimal characteristics of ultrasound tomography for the differential diagnosis of breast cancer. Numerical simulations of various tomographic schemes were performed on a supercomputer. The article compares 2.5D and 3D image reconstruction methods in terms of vertical and horizontal resolution, the computational complexity of the methods and the technical parameters of tomographic scanners. It proposes reconstruction algorithms designed for GPU clusters using the inverse coefficient problem for the wave equation.

For their part, Filatova et al. **[13]** mentioned that the inverse problem of medical ultrasound tomography consists in finding slight inclusions in breast tissue through boundary measurements of acoustic waves generated by sources located at the boundary. Simulations include the solution of direct and inverse problems. First, they calculate acoustic waves for a specific breast model. In addition, they solve the inverse problem using a method based on the visualization of inclusions and the unknown internal boundary between fatty and glandular tissues and resorting to kinematic data to determine the sound velocity in the inclusions. The numerical solution of the direct and inverse problems is based on standard parallel computing libraries (MPI and OpenMP) and is performed on a GPU cluster system.

3.3.2 Supercomputer simulations in the analysis of noise pollution in urban areas.

Mishra et al. **[14]** and Czyzewski and Kotus **[15]** try to analyze the spatial distribution of traffic noise levels in the city of Delhi by creating noise maps with the help of GIS, this being the traditional method for noise map evaluation. Nevertheless, they propose the advantages of three-dimensional analysis by supercomputing in the following analyses.

Lan et al. **[16]** propose mapping the spatiotemporal distribution of road traffic noise in cities to obtain representative road traffic noise maps for different periods. This is a model. Spatio-temporal properties obtained from data from various sources. It is calculated using an efficient algorithm that saves 90% of the time of calculating the noise distribution corresponding to different time intervals. An average absolute error of 2.26 dB [A] is within the acceptable range, demonstrating that this method is effective.

Yang et al. **[17]** developed twenty-four-hour noise maps of Chancheng district in Foshan, China, for this study, and the following results were analyzed: the average equivalent sound pressure level of the entire study area indicates that the noise pollution is modest, it was also found that the noise level of the city is higher during off-peak hours than during peak hours, probably due to the higher speed and higher volume of traffic during off-peak hours.

Cai et al. **[6]** present a systematic methodology to compute urban traffic noise maps in 3D complex building environments by supercomputer simulation, where a parallel algorithm focused on controlling the computational nodes of the supercomputer is designed. In addition, a representation method is provided to visualize the noise map in real-time. Two efficiency experiments are implemented. One experiment involves comparing the expandability of the parallel algorithm with various numbers of compute nodes and various computational scales to determine the expandability. The other experiment compares the computational speed between a supercomputer and an ordinary computer; the compute node of Tianhe-2 is six times faster than that of an ordinary computer. Finally, clusters of buildings have been found to have an apparent protective effect on traffic noise.

Szczodrak et al. **[18]** presented an innovative supercomputing network service dedicated to noise threat assessment. Selected experimental results achieved by using the proposed services were presented. The assessment of environmental noise threats includes creating noise maps using online or offline data acquired through a grid of monitoring stations. Connecting the noise map grid service to a distributed sensor network allows noise maps to be automatically updated over a specified time. In addition, the software estimates the auditory effects caused by noise exposure through a modified psycho-acoustic hearing model based on the calculated noise level values and the given exposure period.

Deng et al. **[19]** integrate building information modeling (BIM) and 3D GIS to represent the built environment in a model by integrating traffic noise assessment of outdoor and indoor environments into a single BIM-GIS platform. It has a high level of BIM detail. Important parameters such as absorption coefficient and TL can be extracted directly from BIM for noise calculation. The Italian CNR model is modified to perform the noise calculation applied to the platform. This paper details the development of a BIM-GIS noise mapping platform based on ArcGIS.

Czyzewski et al.. **[15]** and Czyżewski et al. [20] also present a simulation model for acoustic noise distribution and assess its adverse effects in short periods within large urban areas due to the use of a supercomputing cluster.

3.4 Item selection

In Figure 2, it can be seen that, of the 20 selected articles, 10% corresponded to viewpoint 1 (simulation by supercomputing), 10% focused on viewpoint 2 (acoustic simulation by supercomputing) and 80% on viewpoint 3 (Applications of acoustic simulation by supercomputing).

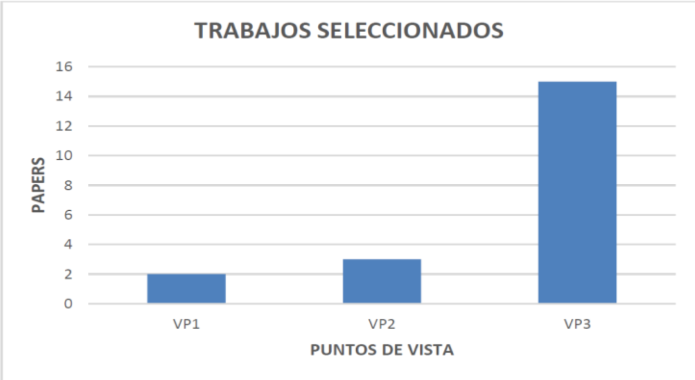

Figure 2. Selected studies

Figure 3 shows the main journals from which the selected papers were obtained. Forty-five percent were obtained from Springer, 20% from Science Direct, 25% from Google Scholar and 10% from Research Article and Journal Physics.

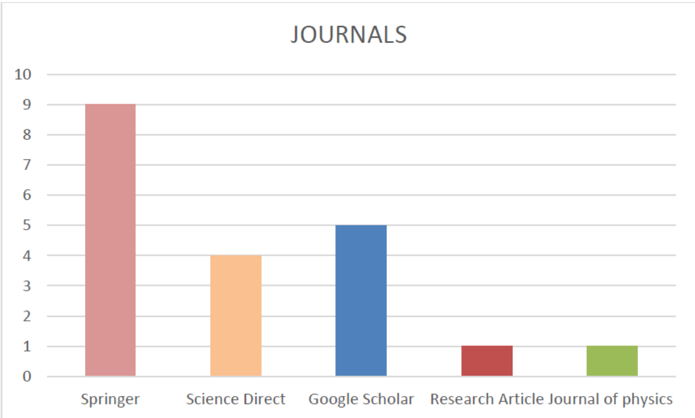

Figure 3. Selected works

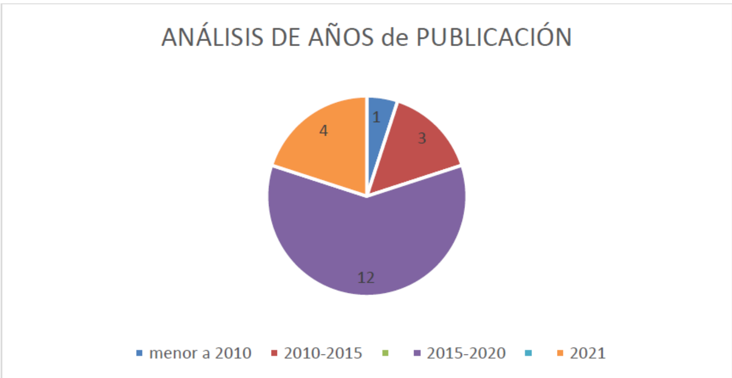

Figure 4. Analysis of years of publication.

(4) DISCUSSION

4.1 Research questions

The 20 articles contain the information necessary to understand the subject of sound wave simulation and the effects that these produce on occupational health. The answers to the questions posed in Section 2.1 are presented below.

PI1: What is supercomputing?

Supercomputing is the application of computers with high data processing while performing real-time simulations demanding a many-core CPU and GPU to be able to run the algorithms in a relatively short time... [2] [3] [3]. **[2]**.

PI2: What is the importance of supercomputer simulation of acoustics?

Supercomputing Acoustic Simulation has emerged as a subdiscipline of acoustics, which is concerned with combining mathematical resolution algorithms and numerical solution algorithms to approximate acoustic fields with supercomputer-based modeling and simulation, whereby acoustic propagation is mathematically modeled through the wave equation. This continuous partial differential equation admits wave solutions. Otherwise, it could not be solved **[1]**.

PI3: What are the advances generated with supercomputing acoustic simulation?

Apart from applications in physics, there are important advances in medicine, mainly in ultrasound devices. Traditionally, these studies resulted in 2D images of our body, but with data processing in a supercomputer, three-dimensional images are possible, making the specialist's diagnosis more precise **[5]**, **[13] [9]**.

With the same principle, materials or welded joints can be analyzed through ultrasound. By obtaining a 3D image of the material's behavior. It can be more accurate in its evaluation **[12]**, **[9]**.

Finally, noise mapping of urban areas over time is possible thanks to simulation since it collects pollution data, processes it and can make approximations as a function of time, improving noise mitigation plans and monitoring **[14]**, **[16]**, **[11]**, **[3]**, **[18]**.

4.2 Paper selection analysis

As can be seen, most of the papers provide the scientific basis for supercomputing acoustic simulation. In addition, these papers generally contain a critical review of the scientific and technical information available on the various modeling algorithms for solving each acoustic problem posed.

On the other hand, the application of the PRISMA guide in several stages in order to select the articles meticulously analyzed in this literature review allows for maintaining a clear and transparent method for the collection of the essential papers that have been investigated up to the present date and have allowed to understand in a large percentage the acoustic simulation by supercomputing.

(5) CONCLUSIONS

In the research of acoustic simulation by supercomputing, a supercomputer must have many cores in its processor and graphics card (CPU, GPU) to perform the processing and simulation in parallel mainly, which helps to obtain the result in a much shorter time concerning an everyday computer. Moreover, since it is in charge of solving equations, one normally would be unable to solve them.

The acoustic simulation allows to solve or transform the complex wave equation to a domain of better processing or solution, giving access to a certain point of analysis of the acoustic problem, as well as to the solution of problems of optics, electromagnetism, astronomy and other branches of physics.

Advances in the field of medicine allow the medical specialist to give a better diagnosis to the patient by being able to observe a 3D model of the human body after the application of tomography. Also, in the analysis of objects with the same principle of analysis.

Finally, with the growing number of people in urban areas, noise is beginning to be seriously considered a factor to be analyzed in the inhabitants' quality of life. For this reason, with a dynamic study of noise propagation at different times of the day, we can diagnose and implement noise pollution mitigation plans in urban areas.

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