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IMPROVING AUTO-CALIBRATION OF GA-BASED SIMULATIONS THROUGH A STATISTICAL ABSORPTION DATABASE

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ABSTRACT

In room acoustic modeling, digital geometric room models are commonly created to aid acousticians in comparing different possible changes that could be made to a room. It is critically important to have the simulated room parameters match the measurements from the real room, so acousticians can have confidence in their design decisions [1]. When calibrating, acousticians will often utilize various optimization techniques to help expedite the alignment of room metrics like reverberation time (T30) and speech clarity (C50). Although auto-calibration technologies provide a large benefit, they run the risk of violating physical realism due to the manual human element being largely removed. To prevent the calibration from producing non-realistic solutions, it is necessary to implement boundaries corresponding to the natural ranges of acoustic properties for common materials. This paper explores how a statistical database that includes mean and standard deviation measurements for absorption coefficients can be used to account for variance in the GA model. The database aims to minimize "guesswork" in estimating the error of GA models by allowing for absorption coefficients to be empirically derived as opposed to being estimated by the acoustician.

Keywords: *room acoustics, geometrical acoustics, auto-calibration, absorption database.*

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1. INTRODUCTION

GA-based modeling methods are used in room acoustic modeling to assist with the analysis of a given space. GA models allow for faster simulations of sounds in rooms by not accounting for the full wave equation during computation [1]. It is critically important to have matching simulated and measured room parameters in order to assure the accuracy between the model's sound field and the measured room. Uncalibrated GA models' parameters can easily deviate from measured room metrics due to a myriad of errors accumulating during the modeling and absorption assignment process. To combat this, acousticians have historically performed a manual calibration procedure to align simulated parameters such as speech clarity (C50) or reverberation time (T30) with values measured from the room [2]. This manual calibration procedure gives the acoustician greater control, but at the expense of being quite time consuming. The acoustician has to ensure absorption coefficients stay within a reasonable range while deciding what planes cause the most significant parameter change given relevant source and receiver positions. Further background on GA-calibration and room absorption measurement error will be provided to illustrate the impetus for a statistical absorption database.

2. BACKGROUND

2.1 History of Auto-calibration and GA Models

The main principle of GA modeling is that sound propagation is modeled using rays cast from a source position to a receiver. The resultant interactions between rays and planes in the model create an approximation of the room's acoustic properties, though it has been shown that uncalibrated models can carry a significant deviation from the real-world environments they are trying to capture.

More recently, heuristic and meta-heuristic software-based approaches have been explored to aid in automating GA calibration [3]. Early research focused on the need to calibrate global parameters (T30), before calibrating direction-dependent metrics. In addition, a rigorous six step calibration process has been established which helps account for more complicated acoustic properties [2]. The most developed calibration tool utilizes a large parameter-space machine learning technique based on concepts taken from Darwin's Theory of Evolution, called a Genetic Algorithm, to optimize simulated absorption and scattering parameters [4]. Genetic Algorithm-based calibration has been integrated as a tool into the popular GA software Odeon and it has already been utilized to perform calibrations in large acoustic modeling projects [5]. Non-ML based auto-calibration methods have also been explored on small scale simulations where plane prioritization algorithms have been used in conjunction with numerical optimization to calibrate T30 and C50 parameters [6].

2.2 History of Absorption Measurement Error

Absorption coefficients are typically measured using impedance tube or reverberation chamber methods [7]. For impedance tube measurements, the absorption coefficient is measured by propagating sound from a speaker at one end of the tube and measuring the intensity of which it reflects back as delineated in ISO 10534-2 [8]. It is important to note that impedance tube measurements are restricted to reflecting the normal incidence sound absorption coefficients of materials [9]. The reverberation chamber method as defined by ISO 354 measures the sound absorption properties of materials by placing a sample of the material inside a reverberation chamber assumed to have a highly diffuse sound field [10]. The random incidence absorption coefficient of the material can be derived from the differential between the empty and material-introduced reverberation time measurements [7].

It has been shown through various studies, that experimental variables for impedance tube and diffuse field measurements can produce significant variation between reported absorption coefficients [11]. Material-based experiential variables like thickness, density, flow resistivity etc. combined with manufacturer tolerances can have significant impacts on both measurement methods. In addition, "material assignment error" can be introduced into acoustic projects as they are often estimated by visual inspection [12].

3. METHODOLOGY

For this study, meta-analysis was conducted by aggregating absorption data in the following categories: *unpainted brick*, *painted or glazed brick*, and *wood floor*. Naturally, there is a tradeoff between the specificity of the material, and the prevalence of unique measurements given the qualifiers needed to meet the label. The generalizations of the labels were constructed according to what an individual might be able to initially discern about in-situ materials in a space. The choice of bricks and wood flooring as materials for absorption coefficient modeling is based on their ubiquitous use and the wide range of construction variations available. This presents a significant challenge for accurately estimating absorption coefficients due to the potential for error resulting from the diverse array of brick/wood types and construction methods [13].

Larger format databases like PTB's Room Acoustics Absorption Coefficient Database [14] and various tables of compiled absorption coefficient measurements by Vorlander [15] and Cox and D'Antonio [16] were used to initially find measurements, however attribution has been given to primary source documents to preserve a more detailed referencing structure, and to exclude duplicate or cross-referenced measurements in the aforementioned databases. [14, 17–24]. It is important to note the prevalence of non-academic absorption coefficient resources available, and the possibility that those could include unique but not verifiable absorption measurements.

4. RESULTS

A total of nine, eight and twelve values for the absorption of *unpainted brick (UB)*, *painted and glazed brick (PGB)* and *wood floor (WF)* were aggregated respectively. Per-frequency band standard deviations represented by error bars on the following figures were computed for each measurement category. When ranked in ascending order for the first three frequency bands, the categories followed a pattern of *PGB*, *UB*, *WF*. For the mid-ranged to higher frequency bands, the order shifted to: *PGB*, *WF*, *UB*, with *WF* standard deviations dropping considerably. *PGB* absorption values had the most similar σ values through all frequency bands, however *UB* standard deviations increased with frequency. These findings imply that the degree of variance for a given label could be correlated with the invisibility of the construction method. It is reasonable to conclude that uncertainties related to the construction methods may result in significantly greater variances in absorption compared to uncertainties related to surface covering methods (eg. painting, glazing, plastering etc.).

When compared with other mean absorption coefficient data such as the *walls hard surfaces average* measurement found in existing absorption coefficient databases [14, 15], the measurements in Fig. 1 and Fig. 2 correlate across the frequency domain however they respectively overshoot and undershoot the generic average measurement value. Values in Fig. 3 are negatively correlated despite the semantics of the average measurement including hard floors. This further supports the hypothesis that construction methods result in greater variances, and it emphasizes the need for statistical accompaniment when reporting average measurements.

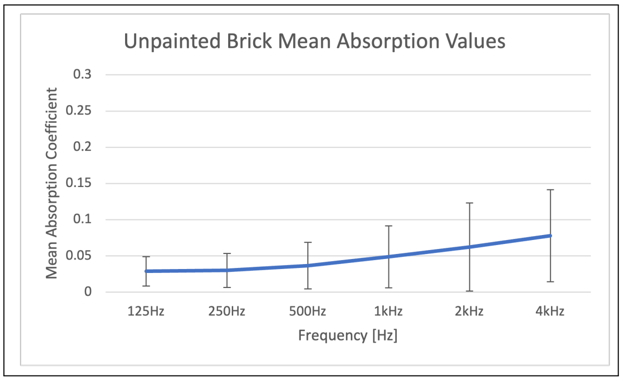

Figure 1. The mean absorption coefficients per frequency band of unpainted brick are [0.029, 0.030, 0.037, 0.049, 0.062, 0.078].

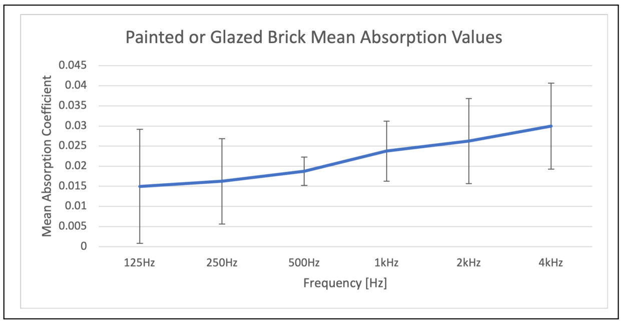

Figure 2. The mean absorption coefficients per frequency band of painted or glazed brick are [0.015, 0.016, 0.019, 0.024, 0.026, 0.030].

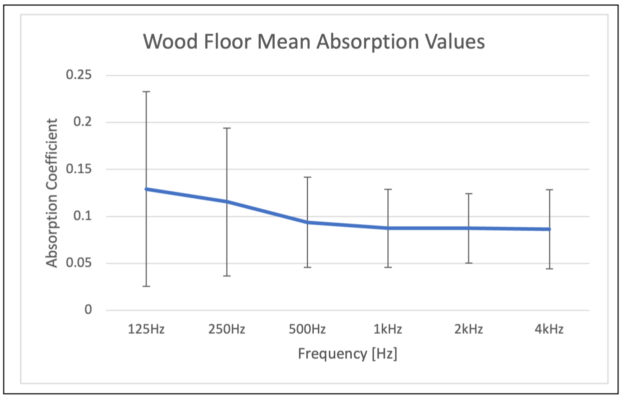

Figure 3. The mean absorption coefficients per frequency band of wood floor are [0.126, 0.111, 0.090, 0.084, 0.084, 0.083].

5. CONCLUSION AND FUTURE WORK

These findings clearly support the use of auto-calibration algorithms for unknown materials/construction methods that could be sources of error in a GA model. These findings corroborate previous literature stressing the importance of search ranges with the purpose of ensuring that auto-calibration algorithms produce realistic solutions [4].

In conclusion, the process of deriving a reasonable range of absorption values requires a careful examination of absorption data to ensure accuracy. This statistics-based methodology not only enhances the reliability of the models but also helps determine with greater accuracy whether their calibrated measurements fall outside commonly accepted absorption values. Furthermore, machine learning algorithms require well-defined rules to generate realistic solutions, which underscores the importance of investing in methods that can produce such rules [4].

Future work includes expanding the dataset of materials and measurements. With a larger library of measurements, categories with greater specificity can be used to provide a better picture of the general absorption for more specific material construction methods. Furthermore, future development steps can be implemented to present the database as a tool for evaluating and comparing different material measurement methods.

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7. REFERENCES

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