Using virtual modeling to improve the acoustics of a classroom

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Introduction

Verbal communication has been with humanity since the dawn of time, and as we have evolved so have our methods of communication. As a society, we text, call, and email, but the main form of communication continues to be sound. The study of sound began in the 6th century with Pythagoras, a Greek philosopher who wanted to study the way strings vibrate. Up until the early 20th century, acoustics was closely related to math and was not a major consideration in the design of buildings (Ermann, 2015).

The field of architectural acoustics began with Wallace Clement Sabine, who created the universal formula for reverberation time and propelled acoustics into the modern day, all while working on the Fogg lecture hall at Harvard (Ermann, 2015). Now, acousticians serve as contractors, working closely with engineers and architects to better design structures. Acousticians no longer need pen and paper; instead, a machine measures the acoustics of a room and acousticians interpret those results. To examine the acoustics of a space before it is built, acousticians use virtual modeling and calculations. However, due to long calculation times and a lack of detail in those virtual models, acousticians are skeptical of calculations produced via these virtual models (Siltanen et. al., 2008). The purpose of this project was two-fold: to use virtual modeling to improve the acoustics of a classroom and to determine the accuracy of virtual calculations by comparing them to the real-world data gathered via an acoustical measurement tool.

Materials and Methods

The blueprints of Aberdeen High School were measured using Adobe Acrobat and the resulting measurements, combined with measurements done by hand, were used to build a virtual model of room B304 in the modeling software SketchUp (Figure 1). Afterward, the finalized virtual room was imported into CATT, an acoustics modeling software, which generated data on the time it took for an impulse sound to drop by 60 decibels (T60) by extrapolating it from the T20 and T30 values. The model was used to estimate the effectiveness of the improvements before testing them in the actual classroom.

Next, the physical classroom's T20 and T30 values were measured using a Brüel & Kjær type 2250 sound level meter (Figure 2). The reverberation time was measured by popping balloons around the classroom and measuring how that impulsive sound decayed. The data collected by the sound level meter was reported using the BZ-5503 measurement partner suite.

Figure 1 (above): The finished virtual model in the program SketchUp, the white square (1 ft by 1 ft) is for scale.

Materials and Methods (continued)

Based on this data, improvements were designed in Fusion 360 and imported into the classroom in SketchUp. Subsequently, the virtual improvements were physically built and put into the classroom. These improvements included sound-absorbing vent covers (Figure 3) and freestanding sound-absorbing panels (Figure 4). These improvements were assembled using wood, screws, Guilford of Maine textiles, egg crate foam, and magnetic vent covers. They were tested, and the resulting data was stored in the measurement suite.

Figure 2 (above): Brüel & Kjær type 2250 sound level meter.

Figure 3 (above): Constructed vent covers (2 ft by 1 ft).

Figure 4 (above): Sound-absorbing panels (30 in. by 44.5 in.).

Results

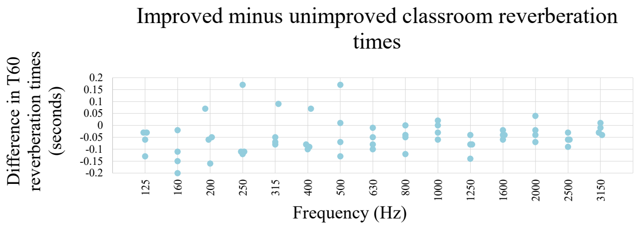
Initial testing of the room revealed that the room had a mean T60 value above the acceptable range (0.2–0.5 seconds) (Ermann, 2015). Multiple sound-absorbing panels and vent covers were built and tested to lower the T60 values. Data was collected from 15 octave bands (Graph 1). Twelve paired *t*-tests ($n = 4$), and three Wilcoxon signed rank tests, due to a lack of normality in the data distribution for these three octave bands ($n = 4$), were run. The resulting *p*-values showed there was only a significant difference in T60 values for 125, 160, 630, 1250, 1600, and 2500 Hz (Table 1). At these octave bands, the alternative hypothesis that the difference in T60 values was less than zero was accepted.

A paired sample *t*-test was performed to compare the machine data ($M = 0.611$, $SD = 0.117$) and virtual data ($M = 1.928$, $SD = 0.323$) from CATT, and showed that the virtual calculations were significantly higher than the machine data on all tested octave bands, $n = 20$, $t(19) = 21.63$, $p < .001$ (Graph 2). Five paired *t*-tests were run, one for each octave band, and the resulting *p*-values confirmed the overall analysis.

Octave band	Room type	Mean and standard deviation	Paired *t*-test
125	Improved	$M = 0.640$, $SD = 0.054$	$t(3) = 2.65$ $p = .038$
	Unimproved	$M = 0.703$, $SD = 0.040$	
160	Improved	$M = 0.718$, $SD = 0.078$	$t(3) = 3.15$ $p = .026$
	Unimproved	$M = 0.838$, $SD = 0.085$	
630	Improved	$M = 0.605$, $SD = 0.019$	$t(3) = 3.06$ $p = .027$
	Unimproved	$M = 0.665$, $SD = 0.033$	
1600	Improved	$M = 0.493$, $SD = 0.029$	$t(3) = 4.90$ $p = .008$
	Unimproved	$M = 0.533$, $SD = 0.026$	
Octave band	**Room type**	**Mean and standard deviation**	**Wilcoxon**
1250	Improved	$M = 0.468$, $SD = 0.042$	$z(3) = 0$ $p = .05$
	Unimproved	$M = 0.553$, $SD = 0.005$	
2500	Improved	$M = 0.470$, $SD = 0.019$	$z(3) = 0$ $p = .05$
	Unimproved	$M = 0.530$, $SD = 0.012$	

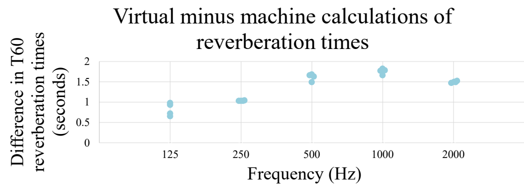
Table 1 (right): Results of the paired *t*-tests and Wilcoxon signed rank tests that indicated a significant difference.

Results (continued)



Graph 1 (above): The difference in reverberation times between the unimproved and improved classroom.

Graph 2 (right): The accuracy of the computer compared to the machine calculations.



Conclusions

The purposes of this project were partially met; the inexpensive physical modifications to the classroom only statistically significantly lowered the T60 value at six octave bands, although it remained above the acceptable range. Additionally, there was a significant difference between the machine and virtual calculations indicating that more detail is required in a virtual model for proper simulation of the acoustical environment. The limited accuracy may be explained by the materials available for virtual simulations, for example, the simulation may not have been able to account for the perforated ceiling in room B304.

Sound-absorbing panels are generally better at absorbing sound at high frequencies compared to low frequencies, because of the wavelength and the physical properties of the material. In theory, the reverberation time should be the same throughout a space. Future research could involve acoustically testing a variety of different materials both virtually and physically to determine if there are any differences in the data collected. The data collection process should also be tested in a variety of different rooms.

References

Ermann, M. (2015). *Architectural Acoustics*. John Wiley & Sons, Inc.

Siltanen, S., Lokki, T., Savioja, L., & Christensen, C. L. (2008). Geometry reduction in room acoustics modeling. *Acta Acustica united with Acustica*, *94*(3), 410–418. https://doi.org/10.3813/AAA.918049