Modern technologies in acoustics and lighting teaching and practice

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ABSTRACT: With the promise that new technologies, and in particular smartphones and virtual reality, may make everyday life easier, numerous apps have been created over the last years for the architectural lighting and acoustic assessments of buildings. This trend opens new opportunities for teaching acoustics and lighting. Meanwhile, the possibilities of augmented and virtual reality are still largely unexplored. The pedagogical aim of exploring new pedagogical approach is to allow students to engage beyond the traditional building physics approach to these subjects and to get a better quantitative and experiential understanding of light and sound parameters. First, the possibility of massive use of auralization is described. Then, the present paper discusses some opportunities for introducing building acoustics and lighting assessments through apps in both courses and architectural studios. The goal is to support experiential learning opportunities for concepts such as the warmth or the enveloping of a space from both an acoustic and lighting perspective. Many questions raised from the first few years of experiences in using smartphone apps are discussed. Comparing different apps on the same or on different smartphones resulted in significant fluctuations in the observed quantities. Since illuminance or sound levels were better detected with professional tools than by smartphones, several challenges of using these apps are discussed. Knowing the limits of current smartphone apps, this paper reflects on how much apps could be integrated into both university teaching and practice approaches. The experience confirmed that smartphone apps cannot yet replace professional measurement tools, while there is evidence about the benefits that modern technologies and in particular virtual reality, can provide to architectural acoustic and lighting teaching and practice.

KEYWORDS: acoustics, lighting, smartphone, augmented reality, virtual reality, app.

INTRODUCTION

This paper aims to reflect, based on the experience of the author, on the way in which acoustics and lighting are taught to architectural students and to which benefits modern technologies could provide to the pedagogy of these disciplines. A few years ago, the author faced the challenge to innovate the III-year undergraduate course “Light/Sound in Architecture” at Ryerson University in Toronto, Ontario. The goals of this course, similar to many courses offered in the third or fourth year of architectural programs in North America, are “*to develop a basic understanding of lighting and sound and to become familiar with the primary modes of characterizing and quantifying light and sound in engineering terms. Basic design concepts and techniques used to manipulate and control sound and light in buildings will be explored*.” Such a comprehensive learning outcome is not easy to achieve, especially considering that usually the introductory teaching of these subjects to students of architectural departments starts without the knowledge of basic physical background.

Acoustics is a broad discipline, strongly based on physics. Its applications nowadays cover several areas: from biomedical to aerospace, architectural acoustics or vibration control. Similarly, also lighting is a broad discipline, which in the building sector is often considered within the domain of electrical engineers whenever it refers to artificial lighting, but an integrated design requires its integration with both layout and façade design.

In order to understand some of the characteristics and constraints of the course of “Light/Sound in Architecture”, it is useful to point that this course consists of 12 lectures offered once a week for 3 hours each. Typically, this lecture course was taught in large classrooms with over 100 students attending it. The course used to dedicate six classes to acoustics and six to lighting, a surely short time to deliver its content properly and deeply. In fact, through the course, students were asked to master the design criteria and analysis procedures for the acoustic and lighting design from simple rooms up to performance spaces or museums.

Traditional, the course content of this course was divided into two modules. For the acoustics module included a general introduction to the fundamentals of sound, sound sources, and sound propagation; subjective and objective scales of measurement and laws of psychoacoustics; relationships between sound and listener in different scenarios: source and listener outdoor or in a room; noise control in buildings; building treatments for airborne and impact sound insulation. A similar approach was taken for the lighting module, with classes that covered first the basic principles of lighting and then looked into the design of lighting systems and the assessments of lighting quantity and quality in different building typologies.

The course has been traditionally based on describing acoustics and lighting using photos and graphs, while a visit to a notable performance space or a museum allowed students to discuss the spatial sense of a room, but often it failed at providing the experience of comparing different attributes of a room. Moreover, one of the elements that emerged in teaching this course is the somehow limited attendance of students who believe that the no-studio courses would deserve less attention than design courses. In the case of subjects such as acoustics, which is perceived as an engineering discipline with strong bases into physics, often students also consider such a course far from their future architectural profession. As such, and based on the many years of teaching experience of the author both in the U.S. and in Canada, it is evident that new pedagogical approaches are clearly needed.

1.0 TEACHING ACOUSTICS AND LIGHTING IN CANADA AND AT RYERSON

The process of updating the teaching approach of acoustics and lighting for architectural students started with the analysis of other similar courses offered across Canada. Currently, there are 11 university schools of architecture which have been granted CACB Accreditation in Architecture (CACB, 2017). Based on the information available on the websites of these programs, the analysis showed that while the *Bachelor in Architectural Science* program at Ryerson University as well as the programs in some other institutions include into a single course the contents of lighting and acoustics, many programs ignore the subject of acoustics in a specific manner (Table 1). The common reason behind this decision could be also related to the lack of a faculty member with expertise in acoustics or the other competitive requests to get the accreditation, which do not leave space for a dedicated course about acoustics. The comparative analysis of the available content related to lighting in the several architectural Canadian programs (Table 2) shows a better situation with on average at least one dedicated course, and sometimes more than one.

Table 1. Courses in Canadian architectural schools covering (event partially) acoustic topics.

School	Program Name	Acoustics course code and name
University of British Columbia	Masters of Architecture	ARCH 531 - Architectural Technology II
University of Waterloo	Bachelor of Architectural Studies	ARCH 272 - Interior Environments: Acoustics and Lighting
Université de Montreal	Bachelor of Science in Architecture	ARC 5317 - Lighting Engineering and Applied Acoustics
Carleton University	Bachelor of Architecture	*ARCN 3003 - Theatre Production*
Dalhousie University	Master of Architecture	ARCH 5208 – Acoustics
McGill University	Master of Architecture	ARCH 555 - Environmental Acoustics

Looking more closely into the way in which both the subjects are thought, it seems that these subjects are often treated using a traditional "engineering/architectural design" approach which is challenging when large undergraduate classes with over 100 students need to be offered. Based on some successful experiences from Europe and Australia, it was hence decided to introduce several novelties. For example, modern technologies allowed to create auralizations of different rooms that students could listen at home. Moreover, students were asked to visit and describe both architecturally and acoustically a performance space and to collect an impulse response (a kind of an acoustic fingerprint of a room) which was used to build a large database of performing spaces. This way students were challenges to learn how to survey a room and to experience the interlinked connections between acoustics and architecture. Similar experiences for lighting portion were performed, as reported in the following sections.

Table 2. Courses in Canadian architectural schools covering (event partially) lighting topics.

School	Program Name	Lighting course code and name
University of British Columbia	Masters of Architecture	ARCH 513 – Environmental Systems and Controls I
University of Waterloo	Bachelor of Architectural Studies	ARCH 272 – Interior Environments: Acoustics and Lighting
		ARCH 226 – Environmental Building Design
	Masters of Architecture	ARCH 673 – The Science of the Building Envelope
		ARCH 678 – Digital Lighting Design for Architecture
Université de Montre	Bachelor of Science in Architecture	ARC 5317 – Lighting Engineering and Applied Acoustics
Carleton University	Masters of Architecture	ARCC 5096 – Building Technology I
University of Calgary	Masters of Architecture	EVDA 617 – Architectural Lighting Design
University of Laval	Bachelor of Architecture	ARC 2102 - Light and physical environments
McGill University	Bachelor of Architecture	ARCH 447 – Lighting

2.0 VIRTUAL ACOUSTIC TRIP

The idea behind this new pedagogical model epitomized the ambition of Ryerson University towards applied learning while constantly innovating its offerings in blended learning environments through creating immersive virtual acoustic experiences. In fact, while a great deal of emphasis is placed upon the visualization of space during the design, yet the acoustics of a space is often poorly considered by architects. Based on the architectural data provided by the students or by some partnering acousticians and architects (Fig. 1), the author created a repository of data about performing spaces, including impulse responses and auralization.

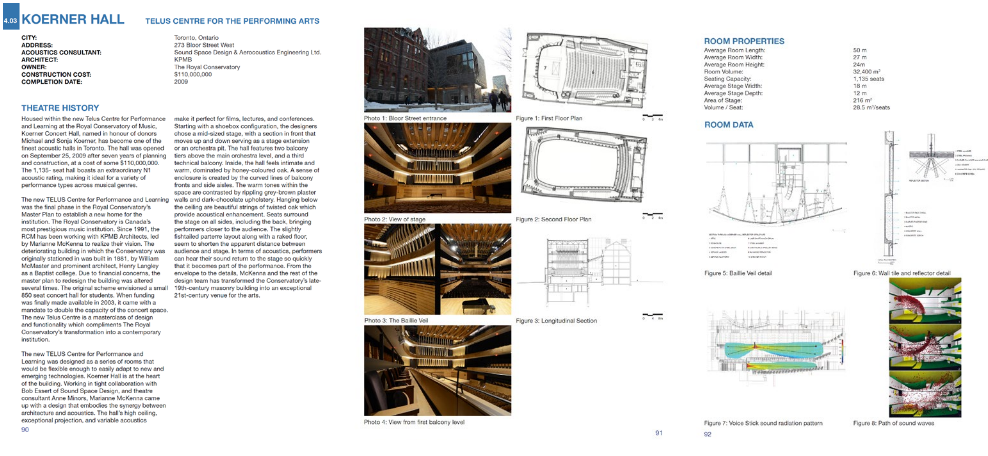

Figure 1. Example of the concert halls description in the e-book.

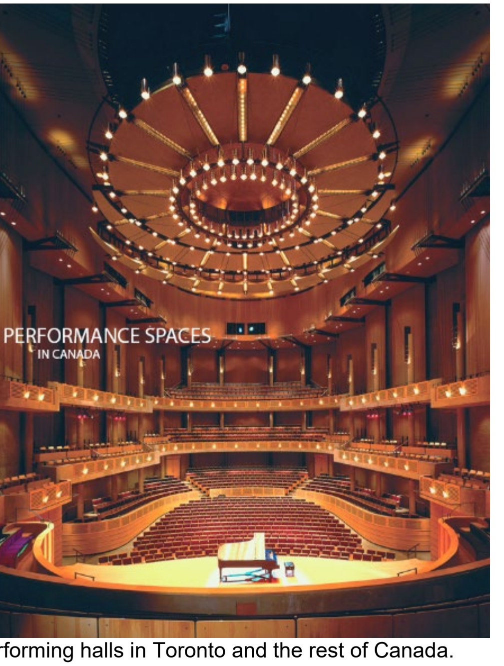

Figure 2. Covers of the two e-books including 70 performing halls in Toronto and the rest of Canada.

The project consisted of creating a repository of concert halls and performing spaces in the GTA and in the rest of Canada (Fig.2), similarly to what has been reported worldwide in textbooks such as Beranek (2003). The impulse response of a room is the acoustic fingerprint of that room, whereas an auralization is the reproduction of a given sound at a point in a room. Contrarily to conventional traditional acoustic pedagogy, this depositary of data enabled students to explore room acoustics beyond class hours and to create a new way to experience a room. Thanks to this effort, and the two new audio e-books (Fig. 2), Ryerson architectural students can now discover the acoustics of main Canadian performing spaces. This intent aimed to enable students to explore room acoustics beyond class hours and to create a new way to experience a room by allowing to listen to auralizations done in different halls. Once the impulse response collection and the auralizations will be completed, it will be possible to conduct a virtual trip in many Canadian performance halls to listen to many different sounds projected in these spaces. Together, the impulse response and the auralization allow users to experience the unique conditions of a room via a “virtual concert”. The intended e-books offer the possibility to listen to different sounds in the same space, allowing to understand the importance of performing a piece of a given music in a space with a particular acoustics, being much more experiential than the technical validation of sound formulas. Thanks to the impulse response recorded so far, students are now able to play impulse responses in order to reproduce the acoustics of famous rooms using their headphones. Qualitative comparative analyses guarantee intuitive but perceived responses to the acoustics of spaces using a binaural reproduction, through high-quality headphones (Fig.3). This experiential learning is considered critical for students’ understanding of current professional design practices and possibilities. The available catalog of acoustic data of concert halls, is now justifying the creation of a proper setup for sound reproduction and listening at Ryerson University. Moving forward, the implementation of an ambisonic simulation environment will be created, eventually in coupling with a Virtual Reality headset, to create new possibilities and a higher level capability for students to listen to the acoustics of a room, similarly to what is available in spaces such as the LIVE (Large Interactive Virtual Environment) Lab at McMaster University.

Figure 3. Acoustics in architecture reproduction: a virtual acoustic trip through auralization or ambisonic (loudspeaker-based) systems.

3.0 THE USE OF APPS FOR COURSE ASSIGNMENTS

Another important novelty was the introduction of the use of smartphones into teaching delivering. Smartphones have evolved into powerful computing machines with exceptional capabilities thanks to built-in sensors such as microphones, cameras, GPS receiver, accelerometers, gyroscopes, proximity, and light sensors. Smartphone developers offer many sound and light measurement applications (apps) using the devices' built-in microphone and cameras. This allowed to base two assignments on measurements done in real life environments with dedicated apps, similarly to experiences done in some architectural engineering programs in the U.S. (Berardi et al., 2014). Typically, acoustic and lighting assessments require the availability and use of specialized and expensive instrumentation technology and data collection expertise, and hundreds of man-hours to assemble and analyze such data. The ubiquity of smartphones and the adoption of smartphone sound measurement apps can have a tremendous and far-reaching impact in this area (Satoh et al., 2016, Sakagami, et al., 2016). The idea was to allow students to experience in real life environments and to do measurements of light and sound parameters, without using expensive devices. Several apps have been created recently both for iOS smartphone and for Android ones for sound level measurements. A total of over 100 iOS apps were examined and downloaded from the iTunes store, as well as more than 60 Android apps. Only around ten apps met some stringent selection criteria for consistency. Recent studies have compared and examined available sound recording apps for smartphones, and have found that only a few apps give good results (Kardous and Shaw, 2014). Unfortunately, these are also the apps that tend to have a cost, and so a proper assessment needs to be done to limit the risks of leaving the selection of the app to use to the students. Results showed that the most iOS devices have somewhat reasonable precision, e.g., for SPL measurement it is similar to Class 2 sound level meter, while several Android devices give lower precision.

Students were asked to use their smartphones for assignments such as: "*in pairs, after having downloaded on your smartphones at least two apps each, conduct measurements of different urban sound environments (with different average sound pressure levels), and discuss the sound level results of the different apps.*" Or "*In groups of maximum three people, after having downloaded on your smartphones two apps each of you, you will conduct measurements of different sound transmission loss measurements of two couples of rooms*". Students could hence figure out common sound pressure levels but also inconsistencies of their devices as they became aware of the limits of these apps and of the importance of detailed reporting and professional writing (Fig. 4).

Figure 4. Samples of the submitted acoustic assignment with acoustic app measurements.

The assignment also focused on aspects such as ratios between low and high frequencies in an effort to allow building in the students, more awareness of qualitative parameters such as acoustic warmth and bass ratios. Finally, students had to discuss the time dynamics and fluctuations of real sounds and how they can impact people both within and outside buildings. SoundOut by Australian Hearing resulted in the app providing the majority of functions and a good accuracy.

Similarly, using dedicated apps on their smartphones, students were asked to perform lighting measurements in different spaces. The idea was to explore students to a direct capability to assess the illuminance and contrast levels in different scenarios. Beyond quantitative assessments of lighting levels, students investigated contracts, shade efficacy, and glares conditions. Then, they had to build models of the room also importing HDR photos and to calibrate rendering in free to use software (Dialux).

Figure 5: Samples of the submitted lighting assignment with app measurements**.**

4.0 EDUCATIONAL OPPORTUNITIES AND CHALLENGES

Many questions raised from the first experiences about introducing new educational approaches in acoustic teaching. Auralization have already proved to represent an important way to allow students to perceive directly the acoustics of a room by projecting different anechoic (e.g. neutral) sounds in it. The availability of an ambisonic setup will allow to overcome the limits of headphone reproduction (head movements, low-frequency cut, etc.).
About the possibility for smartphone apps to replace professional measuring devices and about how much these apps should be included in our teaching. Even though these are only simple tools, they allow students to understand the relationship between their sensation and physical values. For Android devices, the measurement values showed large errors and individual differences, as well as, non-linearity in many devices. On the other hand, iOS devices showed fairly good agreement with Class 2 sound level meters. The results proved that sound pressure level measurements were sometimes poorly detected with smartphones. Comparing different apps on the same or on different smartphones resulted in significant fluctuations in the measured values. This means that smartphone apps are not very reliable, although they represent a resource for enhancing students' participation and engagement beyond class hours. The limits of the app force to rethink their values in order to build a more scientifically

valid exercise. Another key factor would be to have a controlled environment to ensure better results in measurements and eliminating unwanted background noise and lighting sources. The fact that some apps work with so-called calibration functions induces the user to a sense of confidence in their quality, but unfortunately, it is often not possible to set the value accurately. The values outside the calibrated value are subject to extreme fluctuations. In conclusion, even for daily uses, the apps are still not a good way to get a general measurement about the sound and lighting levels of a room.

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