Sound design intervention in an open studio: Linking behavior, spatial, and acoustic analysis

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ABSTRACT: Design studio spaces in Architecture schools are unique classroom settings because two different types of teaching occur simultaneously. Desk critiques and presentations are conducted side by side by multiple professors/students for multiple courses of varying subject matter and skill level in an open-plan setting. The empirical evidence demonstrates that noise pollution effects speech intelligibility, speech privacy, productivity, and satisfaction. This study aims to understand the impact of noise generated by the various instructions occurring concurrently on the learning effectiveness in Architecture schools and to offer design solutions to mitigate noise pollution.

This study combines spatial and acoustic analysis of the architecture design studio at Southern Polytechnic State University and behavioral studies of the inhabitants of the space. These findings can be used to inform design solutions in similar open-plan studio spaces in architecture and design schools.

INTRODUCTION

Architecture studio is the primary space in architecture schools in addition to standard educational spaces of classrooms, individual offices and administrative support. They support the design activities that are central to the curriculum of the architecture school, often including hands-on and collaborative exercises. Unlike the studio layouts used in other parts of the world, the studio space in architecture schools in the US often consists of an open-plan space including student workspaces divided with low partitions. The partitions create visual privacy for the student while they are seated, but once standing they have visual contact with the entire space. While an open-plan benefits visibility, access to daylighting, views of the outdoors, and an ease of communication for group collaboration, the partitions do not offer acoustic privacy. The structure of the courses held within the studio space is also varied, as the professors conduct lecture, desk critiques, informal group lessons, and pin-ups (project presentations). It is common for neighboring studio sections to perform different activities concurrently according to flexible work processes, i.e. while a studio section is involved in quiet individual work; the neighboring section is carrying out a design review that often involves loud conversations and exchanges; oftentimes causing noise distractions for student and faculty. This causes students to have difficulty understanding their professor as instructions or lessons are given and create a situation of lowered academic performance for students.

The requirements of an architecture studio are seemingly opposing, as students and professors need visibility and easy access to other students for group partnership and communication, while there is also a need for auditory privacy and clarity for students learning. A balance through design is needed to create an atmosphere that can nurture the interaction needs of the education process while also preserving the auditory needs for optimal learning.

To date, several studies that discuss collaboration and acoustic properties of education spaces have focused on traditional classroom settings in primary and secondary schools without addressing the unique setting and requirements of architecture studios. This paper aims to bridge this knowledge gap by means of analyzing behavioral, spatial and acoustic conditions in an architecture studio in the context of similar studies carried out in workplace settings. The argument is developed in four parts. First, the paper discusses the analogy between open-plan office settings and architecture studios due to the similarity of collaboration. Second, we discuss the effect of acoustic climate on learning by studying the research conducted in traditional classrooms. The knowledge about the effect of acoustic conditions gained from these studies can be applied to architecture studios since students share the same characteristics in learning. Third, the paper reviews the properties of sound and materials that can be incorporated inside studio settings for the purpose of mitigating the acoustic climate. This information is invaluable to understanding the needs of architecture studios and how to better design for them. Finally, the paper offers a few design solutions aimed at improving the spatial and acoustic properties of open-plan architecture studios.

1.1. Commonalities in layout, work processes and acoustics between architecture studio and den office

Parallels and analogies exist between architecture studio and office layouts as they both support varied and changing activities. Architecture studios have not been thoroughly investigated, unlike open-plan offices that have been extensively analyzed due to the need of corporations to enhance the productivity and satisfaction of their employees. Office settings have been the focus of continued investigation, speculation, and research. The following argument is developed on the knowledge generated in the office design field, given similar work processes of open-plan offices and architecture studios.

Based on Duffy's classification of office settings (Duffy, 1997), we propose to categorize architecture studio as a den given the low degree of autonomy and high interaction. According to Duffy (1997), den spaces are "arranged in an open-plan office or group room and are associated with group work". Though the noise distractions of an open studio are known to those who use them, not much research has been done on these spaces. Architecture studios are similar in construct to open-plan offices. Accepting the strong similarities, one can adopt the lessons learned in the design and research of open-plan offices to better understand architecture studios. Recognition of the correlation between studio spaces and open-plan offices allows one to utilize the vast research conducted on open-plan offices.

According to Duffy (1997), offices were created to house and process large amounts of information created by manufacturing and distribution. In the 1960's the work force begin to specialize, this transformation informed the evolution of the office. With the elimination of corridors and partitions, it was believed that the open-plan layout would increase communication and allow more efficient supervision from management. (Bradley, 2003; Navai and Veitch, 2003). Open-plan offices are preferred by many companies because they are cost effective and promote communication. These offices have connected spaces with low or no partitions in addition to large corridors that encourage unscheduled encounters. This creates an environment where communication is easier, but results in noise pollution.

Since the birth of open-plan offices, scholars have sought to determine the desired benefits of enhanced communication of open-plan are a reality. Many studies have shown the benefits of connectivity in open-plan offices (Duffy, 1997; Hillier and Penn, 1991; Peponis and Wineman, 2002). Meanwhile, other studies have determined that the noise generation and lack of privacy are problematic (Bradley, 2003; Cangelosi and Lemoine, 1988; Evans, 2003). Studies conducted in the 1970's and 1980's observed background noise of open-plan offices of 79 dB(A). The drop in background noise in current studies can be attributed to modern machinery producing less noise; though improved, the ambient noise levels of open-plan offices remains unsatisfactory. Current surveys document noise levels ranging from 46-58 dB(A) which coincide with reports of lowered acoustic satisfaction from workers (Navai and Veitch, 2003). Employee feedback express frustrations of overhearing coworkers conduct business via telephone in adjacent cubicles. Discomfort with auditory stimulus has been shown to correlate directly with absenteeism, high turnover rate, illness, and an overall dissatisfaction in staff. In contrast, an environment that does not experience distraction from auditory stimulus is an important factor in increased productivity.

1.2. Acoustic levels and learning performance in educational facilities

While there are not studies that have specifically addressed architecture studios, we are discussing how an environment with higher levels of noise affects learning. The type of work conducted in traditional classrooms differs from architecture studios in that only one lecture is conducted at a time whereas in architecture studios many courses are conducted simultaneously with varying activities. Regardless of this difference, the importance of lecture and students understanding is the same.

Research has been conducted on the acoustics of classrooms (Crandell and Smaldino, 2000; Dockrell and Shield, 2006; Klatte et al., 2010; Mikulski and Radosz, 2011; Nelson and Soli, 2000) with the focus on primary and secondary schools. There has been limited research on how acoustic conditions influence learning in higher education settings. Though the information gathered is from primary and secondary schools, the data resulting from the studies can be applied to a broad range of student age levels.

Research suggests that classrooms with poor acoustics may generate "a negative learning environment for many students" (Dockrell and Shield, 2004). Prolonged contact with acoustic distractions in a classroom can negatively affect a student's academic performance and information processing (Dockrell and Shield, 2004; Persson et al., 2013). Teaching in a classroom is performed orally from a professor while in return the student learns aurally. This exchange is dependent on the acoustics of the room allowing for the student to hear the professor clearly. This is known as the signal to noise ratio (SNR). Interior room surfaces reflect, transmit, and absorb part of sound energy. If the surface is dense, smooth and reflectivemost of the sound energy will be reflected. If the surface is thin most of the sound energy will transmit through. If the surface has a think porous layer on top of a hard, dense layer, such as carpet on concrete, most of the sound energy will be absorbed.

Decreasing reverberation time will increase the SNR and speech intelligibility. Within an enclosed space sound energy will reflect off many times before it decreases by 60 dB or more. The time (in seconds) it takes for this to occur results in the reverberation time. An increase in sound absorption will decrease the reverberation time. ANSI/ASA S12.60 standard limits the maximum reverberation time to 0.6 seconds for core learning spaces less than 283 m^3 though others suggest the reverberation time not surpass 0.5 s (Person et al, 2013; Treasure, 2007). A potential solution to decrease the reverberation time of the space would be to install materials that are more acoustically absorptive.

Installing absorptive materials to mitigate noise transmission throughout the space is particularly useful in situations such as architecture studios where the need to preserve visual connectivity and communication is imperative to its daily use. The reduction of noise in open-plan becomes difficult, due to sound energy passing over the partition, or diffracting around these partial walls. Acoustic ratings of materials assist in selecting materials that benefit the acoustic climate of a space. The NRC (noise reduction coefficient) is a measurement of the reduction coefficient and the absorption quality of a material, with a rating (evaluated from several frequency bands) ranging between 0 and 1. A rating of 0 indicates none of the sound energy is absorbed, whereas a rating of 1 indicates the material is 100% absorptive. Table 1 documents typical materials in architecture studios and their corresponding NRC rating.

Table 1: NRC ratings of typical materials used in education facilities and architecture studios.

Material	NRC Rating
Concrete block (unpainted)	.05-.35
Concrete smooth (unpainted)	.00-.20
Glass	.05-.10
Gypsum	.05
Wood	.05-.15

1.3. Case study: architecture studio at Southern Polytechnic State University

The architecture studio of Southern Polytechnic State University is located on the second floor of a building constructed in 2000, and is used by third and fourth year students. Each student is given a permanent workstation for the duration of the semester. Workstations have a drawer stack, work surface, and low partitions for pin-up space that also provides electrical outlets. The partitions are composed of metal studs and painted homasote (figure 2). Tasks conducted at workstations vary depending on requirements of the studio, including drafting, sketching, and model building. The structure of a studio changes on a daily basis as professors require desk critiques, pin-up presentations, and group instruction. The effect of alternating activities in adjacent courses often results in one section of students engaging in quiet drawing while the neighboring sections may be involved in loud group projects or instruction. The result of differing activities is a distraction to surrounding students. In addition to the typical noise generated from course activities, many students listen to music, streaming television, or movies as they work.

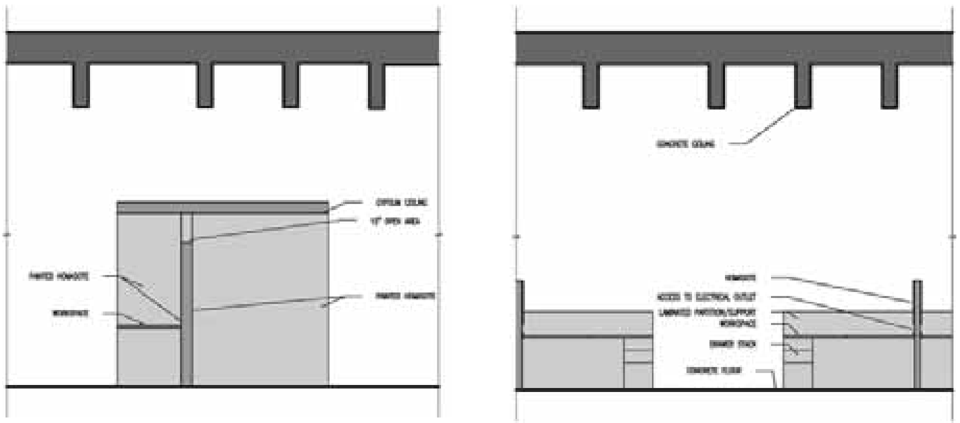


Figure 1: a) Section demonstrating the current conditions of pin-up area. b) Section demonstrating the current conditions of the workspace area.

The current design and configuration of the architecture studio does not mitigate sound generated by the courses it contains, but it does offer several benefits that need to be preserved. The low partitions provide visual access to the entire studio. In addition, they allow natural daylight to permeate the space. Open workspaces create an environment that accommodates group activities and unscheduled individual collaboration between students and professors.

In addition to workstations, the studio also incorporates five pin-up presentation spaces. These spaces have three eight foot high walls constructed of metal studs clad in seven foot high panels of painted homasote and a gypsum board ceiling. (figre2) Students present their work to their peers and professor in these spaces. The presentations are scheduled and unscheduled.

The floor and ceiling are concrete; the ceiling is coated in fire retardant spray foam (figure 2). The north and south exterior walls contain large glazing which allow natural light and outside views. The east and west walls are cinderblock interior walls.

1.4. Acoustic definitions

Sound pressure level (SPL) is a measurement (dB) intended to correlate the intensity of a sound and that effect on the human ear. The scale of decibels is logarithmic, therefore a doubling of sound energy is occurs every 3 dB. However, for the human ear to perceive the doubling of loudness, the sound would have to increase 10 dB (Navai & Veitch, 2003; Treasure, 2011), which is a ten-fold increase in sound energy. SPL ratings are weighted to account for the human ears detection of varying frequencies. The physical properties of a space can either enhance sound by offering ample space for vibration, or retard the sound based on the materials chosen. Sound waves are transmitted, reflected, or absorbed into a material. The utilization of sound absorbing materials drastically reduces sound reflected back into the room. Sound absorbers are composed of porous material with interconnected pores, an imperative property to dampening sound. In addition, the thicker the material is, the more effective it will be at absorbing sound. The absorption coefficient indicates the effectiveness of a sound-absorbing material (Egan 1988). These absorption coefficients vary with frequency. The weighted combination of sound absorption coefficients at several frequency ranges lead to the NRC rating discussed earlier.

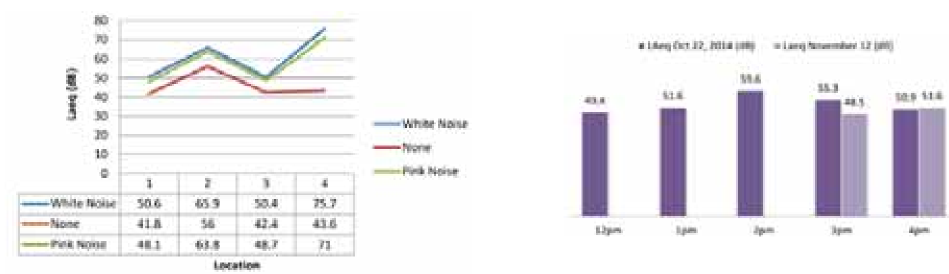
1.5. Sound measurements and experiments within architecture studio

We analyzed the studio space at SPSU using a Larson Davis Model 831, a type 1 sound level meter, following ANSI/ASA S1.13 standard. Calibration of the instrument was performed at the start and end of each daily experiment. Two types of sound experiments were conducted. The first was *in situ* and measured the hourly equivalent A-weighted level (L_{Aeq}) at different locations within the Design Studio. This was done to get an overview of the sound levels throughout a typical day. The second type of experiments was a semi-controlled measurement of a white-noise and pink-noise source at different locations.

For the in situ experiment, sound levels were gathered over the course of two days to ensure most conditions were measured (desk critiques, presentations, and group working sessions). During this time, students' locations as well as students moving through the space were recorded. This information was gathered in order to determine where the most traffic noise is generated in the studio, which can create distraction to other students working. In addition, another session of measurements were gathered during the late evening hours as a control using machine generated white and pink noise to create base levels. Due to cost and availability, a calibrated, standard noise generator and speaker were not available. Instead a phone app was used to generate white or pink noise, and a single small speaker was used to produce the noise. So approximated acoustical white and pink noise signals were not generated. But this is sufficient to determine how noise can affect the students working in a different area. The date, location, and times that the levels were registered are shown in figure 3.

Figure 2: a) The location of audio speaker and sound level meter during the controlled experiment; b) In situ experiment's, indicated the location of sound measuring device during studio and associated date and time interval.

Students and professors were not given prior knowledge to the sound level meter being utilized in the space so no change in behavior would occur. The L_{Aeq} levels generated within the studio range between 49.4 dB and 59.6 dB, as shown in figure 4. L_{Aeq} is utilized to measure the sound generated in the space due to the nature of noise fluctuating over time due to spikes in sound levels. The L_{Aeq} is an A-weighted equivalent continuous sound level. Figure 4 presents the baseline L_{Aeq} readings of the controlled measurements. The use of white and pink noise generated a higher L_{Aeq} measurement then was registered with no acoustic stimulus. A spike in the L_{Aeq} is shown at the second location of the experiment where no acoustic stimulus was generated due to a group of students 15 feet from the sound measurement device engaging in a burst of laughter.



	1	2	3	4
White Noise	50.6	65.9	50.4	75.7
None	41.8	56	42.4	43.6
Pink Noise	48.1	63.8	48.7	71

Figure 3: a) Line graph and chart showing the L_{Aeq} levels for each type of controlled noise generated. 1 is when the noise source was located B and the sound meter at A (ref Figure 1). 2 is when the noise source was located at B and sound meter at B. 3 is when the noise source is moved to C and the sound meter was at D, while 4 is when both noise source and meter were at C. b) Bar graph showing the LAeq levels for each hour of sound measurements taken. Note that the location changed for each hour measured, as shown in Figure 1b.

Students and professors participated in an anonymous questionnaire regarding their perceptions of the acoustic quality of the space. The questionnaire included of questions regarding the speech intelligibility of professors, level of noise distractions, and preferences of when to work in the studio. All students that have classes in the studio space were asked to participate in the study. The results showed that 81% of participating students desk location were in the 2-3 desks near the pin-up space or the 2-3 desks in the center of their studio space, while 66.7% of participants indicated dissatisfaction with the noise level in studio. The main sources of noise referenced were individuals talking with neighbors, music played on a stereo or computer, and people traveling through the space. In addition, 52.4% of students responded they prefer to work in the studio in the morning or late at night, which correlates to responses that these are periods with the least amount of distractions. The Majority of participants (76.2%) responded they would be more productive if the acoustics were controlled more effectively.

1.6. Design intervention

In order to preserve the benefits of the open-plan architecture studio space, we recommend an efficient use of materials to mitigate the noise. To improve the absorption of the partitions of pin-up spaces, the painted homesote will be replaced with unpainted cork (figure 4). This will preserve the pin-up benefits of the wall material while improving the sound absorption for the overall space. In addition, acoustic clouds will be ceiling mounted. This will absorb the noise currently traveling toward the exposed ceiling and reflecting into the space. The floor is to be covered with carpet tile. The carpet will absorb sound within the space while allowing for easy repair, if necessary. These material adjustments will positively affect noise control in architecture studio because they are porous materials that absorb noise transmitted and reflected within the space. By absorbing more noise, the speech/noise ratio is improved as well as decreasing the distractions within the space.

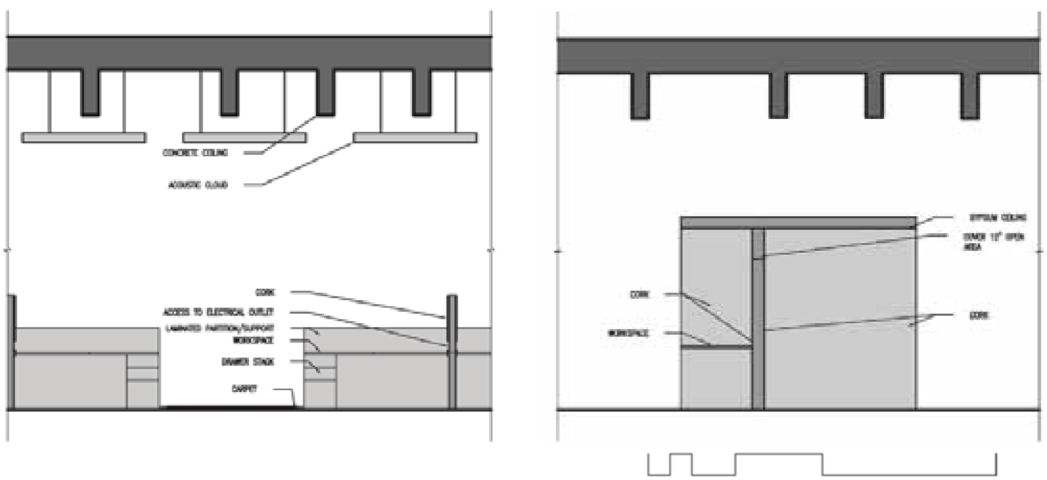


Figure 4: a) Section demonstrating the proposed conditions of pin-up area. b) Section demonstrating the proposed conditions of the workspace area.

CONCLUSION

Architecture studio is at the core of architecture education. For this area of the education to be integral and simultaneously under studied is an interesting problem. Open-plan studio encompasses various benefits, such as ease of communication, collaboration, and a high visibility. Though these benefits need to be retained, open-plan studio also has a large disadvantage; the acoustic properties of the space are less than desirable. The aim of this study was to determine the depths of consequences to working in an environment with poor acoustic properties. In order to achieve this, studies of open-plan offices and traditional education spaces were drawn upon.

Through the physical study of the architecture studio at Southern Polytechnic State University, sound measurements determined sound absorption was undesirable at best. Surveys conducted supported that the noise levels of the studio created an environment of distraction for students. Many students indicated an increase in productivity if the noise were controlled within the space to decrease distractions.

Though further study is needed, the problem has been clearly identified. Creating a collaborative space that incorporates aural privacy is ideal for productivity and satisfaction in architecture studio. A design intervention based on adjusting construction materials is a solution that preserves the visual and collaborative benefits of the open-plan layout while mitigating the negative noise produced within the space. Experimentation with adjusting materials and material placement is the next step imperative to creating a substantial solution. The final results of this study will not only affect the architectural education community, but the design community of any open-plan space as the loss of productivity is documented in other open-plan spaces, such as offices; as the results will have the ability to be replicated in any space with similar parameters. Attention to sound in the design process is undervalued and long overdue.

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