Interdisciplinary research into architecture and music: An evaluation of acoustic performance of a selection of spaces and of materials

Boram Kim

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Interdisciplinary research into architecture and music: An evaluation of acoustic performance of a selection of spaces and of materials

by

Boram Kim

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Architecture

Program of Study Committee:
Michael W. Muecke, Major Professor
Andrea Wheeler
In-Ho Cho

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University
Ames, Iowa
2019

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DEDICATION

I would like to dedicate this thesis to my parents without whose support I would not have been able to complete this work. I would also like to give thanks to my friends and family for their loving guidance and financial assistance during the writing of this work.
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ACKNOWLEDGMENTS

I would like to take this opportunity to give thanks to those who helped me going through conducting research and the writing of this thesis. First, thank you to Dr. Mikesch W. Muecke for his guidance, patience, and support throughout this research and the thesis. His passion and encouragement have often inspired me to succeed in my graduate education. I would also like to thank my committee members for their efforts and contributions to this work: Dr. Andrea Wheeler and Dr. In-Ho Cho.

In addition, I would also like to thank my friends, colleagues, the department faculty and staff for making my time at Iowa State University a wonderful experience. I want to also offer my appreciation to those who were willing to participate in my surveys and observations, without whom this thesis would not have been possible.
ABSTRACT

This research examines the acoustic comforts of different occupational building types and investigates the combination of building elements, especially focusing on building layout and materials that are considered significant sources of unwanted sound. A major part of the thesis relies on a series of sound pressure (decibel) measurements in three distinctive occupational types: residential, educational, and theater buildings on the Iowa State University campus, and evaluates them with the current standard of allowable sound levels. In addition, this thesis analyzes the existing spatial and material strategies of the three types. The selected materials and their acoustic qualities will be investigated and compared with USG Building Acoustic Assemblies. The results reveal poor acoustic qualities and unconcerned acoustic designs of the investigated buildings. Most of the surveyed designs do not meet either the American National Standards (ANSI) and American Society for Testing and Materials (ASTM).
CHAPTER 1. INTRODUCTION

Buildings are based on many variables: materials, structural systems, surrounding environments, economics, users/inhabitants, etc. Designers for contemporary buildings tend to focus on physical and visual materials; however, buildings also engage with the apparently immaterial and invisible, such as sound.

Various building elements can become a source of sound. Services, machines, people, building materials, volumetric forms of space, even outside factors (wind or rain) can cause unwanted sound (noise) inside buildings [1]–[4]. The composite of all sorts of sound sources is usually displeasing and disruptive when one considers the surrounding environment of the building. For this reason, sounds need to be identified and evaluated whether they aid in or disturb users and the design features of the building.

A comfortable built environment is deeply associated with appropriate acoustic strategies as well as thermal and daylight strategies. To allow comfort to the occupants, the architects need to generate a solution that prevents and controls the acoustic environment of the building. Failure in acoustic design can lead to the failure of sustainable and comfortable environments. Additionally, frequent exposure to high levels of noise may result in the occupants having lower satisfaction in their environment, potential disruption of their work, and even their cognitive abilities [5]–[7].

Unlike many former studies that have focused on daylight and thermal performance of the buildings, only general concepts (fundamentals) of acoustics were studied [1]–[3], [8]. Various studies have started to explore acoustic comforts and acoustic environment of buildings and its impact on the user’s perception and behavior [5], [6], [9]–[14]. Besides, among those studies on acoustic comfort, a number of current studies distinguish different
standards and different investigations based on particular occupational types (either residential, educational, or conventional) [5], [6], [9]–[12]. Many of these studies evaluate the acoustic performance of the buildings based on physical measurement (ambient noise and reverberation time) [6], [9]–[12]. Some of the studies evaluate the acoustic qualities based on the subjective perception of the users [13], [14].

This study has chosen university buildings to identify and evaluate undesirable sound or noise. A university is an institution of higher education and research that trains and educates students to be more successful in job decisions and in higher academia. It has a distinctive feature that offers both educational and residential buildings in which students spend most of their college lives on campus. Hence, it is important for universities to obtain a sustainable and comfortable environment on campus to increase the efficiency of learning. The comfort in both living and learning conditions on campus will be evaluated according to the acoustic conditions/performance of the selected buildings [2], [6], [9].

The goal of the thesis is to evaluate the acoustic conditions of three occupational types (residential, educational, and theater) on the Iowa State University campus. Field measurements of ambient noise were conducted and evaluated, following American National Standards, ANSI. Furthermore, former design schemes on acoustics were analyzed and evaluated with respect to their spatial configuration and materiality (qualities of materials and the assembly). The measured and analyzed data were compared with the reference values found in the ANSI S12.60, ASTM E90-9, and in USG Acoustic Assemblies.
CHAPTER 2. METHODOLOGY

The purpose of this study is to verify the acoustic qualities of indoor rooms within three distinctive building types on Iowa State University’s campus, following the national acoustic standards of allowable sound pressure level. It specifically focuses on interior or indoor noise caused by indoor sound sources and transmitted by interior walls.

The study initially takes a quantitative approach (decibel measurement) to collect the data for the intensity of acoustic performance in buildings and conducts qualitative analysis in building layouts and materials with respect to acoustic comfort. This thesis first describes the basic background of the three occupational types: residential, education, and theater buildings that will be evaluated and analyzed in terms of acoustic performance. Measurement of indoor ambient noise will be carried out and expressed by the sound level in dBA [1] and material and layout analysis will be analyzed based on construction drawings provided by the architects and building managers on campus.

Conditions of the Evaluated Buildings

Iowa State University has a wide range of programs and offers various building types that require different acoustic levels and that have different requirements. Among all these buildings on campus, this paper explores three distinctive occupational types: residential halls, educational buildings, and theater buildings, all of which are sensitive to sound transmission and to acoustic control.
Theater type buildings such as concert halls and performance spaces are primarily concerned with sound transmission and proper acoustic environments. The ISU Music Building, an example of a theater building at ISU designed by Durrant Architects Inc, is located on the south side of the ISU campus, directly north of Lake Laverne. Music Hall, which opened in 1978, went through one replacement and several remodeling processes in order to accommodate more music-purpose rooms and more music majors. The current building is composed of large ensemble rehearsal rooms, small ensemble rehearsal rooms, a percussion practice room, an instrument repair facility, practice rooms, and a recital hall. The building is known for its excellent acoustic qualities. The form of the building, a solid concrete box, was intended to include the best acoustic practices for the users: students, faculties, and the public who wants to visit the performances.

Similar to theater-type buildings, residential buildings also need to be carefully designed in terms of acoustics. One of the reasons is that residential campus buildings are
intended to offer privacy, but the units tend to be clustered, and each one shares at least one wall with the next unit. The result is that many residents in townhouses, residential halls, and apartments are distracted by unwanted noise from their neighbors. To properly study residence halls, this paper examines a total of three residential buildings on the ISU campus, namely Helser Hall, Frederiksen Court, and Geoffroy Hall.

![Helser Hall West Entrance](image)

**Figure 2.2 Helser Hall West Entrance**

Helser Hall is located at the center of the ISU campus. It is in the busiest area with major circulation all day long. The building was originally built in 1957 as an all men's residence hall, but women's residential units were also added later on. Helser Hall is one of the oldest residential buildings on campus. Walls, windows, doors, and mechanical systems, such as the air handling units, are outdated. Constant noise is caused by the window air conditioners which are attached to the windows outside.
Geoffroy Hall is the newest residential hall on campus, designed by KWK Architects in 2017. It boasts one of the best sound strategies among the other residential halls on campus. The building serves three major functions, namely study areas, social gathering spaces, and residential units. While the building serves multiple public and private programs, it tries to separate those private and public areas by floors; most of the public programs are located on the first floor, and from the second floor to the top floor there are only residential rooms, service spaces (restrooms, showers, and electric cabinets), and small gathering spaces (study rooms and lounges).
Frederiksen Court is situated on the north side of campus. It is an apartment type residence. The block has about thirty identical buildings, and each building has three floors and thirty living units. Each apartment building has one elevator at the center and an emergency exit stair at each of two corners of the building. Each apartment block includes one communal space at the center of the block for social gathering and food services.
Lastly, educational buildings—especially studio-based buildings—are less concerned with the acoustic environments than those two previous building types; however, they are still required to follow certain standards. The College of Design, an educational and studio-based building, is located on the north-west side of the ISU campus. The building consists of five stories, plus a ground floor, of both studio classrooms and offices that wrap around an atrium open throughout floors 1 through 5. The main building was constructed in 1978 and now offers seven design programs and several interdisciplinary programs related to design. The adjacent King Pavilion was added to the north of the main building in 2009 to provide more space for design students.

**Measurement of Indoor Ambient Noise**

The evaluation of the subject buildings requires careful considerations of both time and weather. The experiment was conducted in empty rooms of each building during a certain time period: 1. during normal class hours and 2. during weekends (only for the
residential buildings). The ambient noise; background noise was measured by a decibel meter and expressed in decibels [2]. As well as the time, because sound levels are highly influenced by humidity level, certain conditions such as rain, wind, and thunder were avoided [15].

As mentioned above, the data were obtained in three different types of buildings. Specific programs were chosen in each building. Noise levels inside of the buildings and inside of specific rooms were measured to verify whether the acoustical conditions of the rooms are comfortable enough to learn and live on campus. The influence of noise from indoor sound sources was also examined.

During the measurement, a BAFX3608 decibel meter was positioned on a tripod and placed at the center of the space or room. The duration of each measurement was 10 to 15 minutes. The continuous equivalent sound level was thus obtained, along with its range of variation within the levels. The result of the collected data was compared with the allowable sound pressure level (shown in table 2.1 below).

Table 2.1  *Table of the acceptable room – The table shows appropriate sound levels for each type of room*[3], [16].

<table>
<thead>
<tr>
<th>ROOM/SPACE</th>
<th>DBA</th>
<th>NR</th>
<th>NC/NCB</th>
<th>RC/RCM2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theaters, Concert Halls, Recording Studios</td>
<td>25-30</td>
<td>20</td>
<td>10-20</td>
<td>20</td>
</tr>
<tr>
<td>Living Rooms, Classrooms, Lecture Halls, Conference Rooms</td>
<td>30-35</td>
<td>30</td>
<td>30-40</td>
<td>30</td>
</tr>
<tr>
<td>Offices, Courtrooms, Private Work Rooms</td>
<td>40-45</td>
<td>35</td>
<td>30-40</td>
<td>35</td>
</tr>
<tr>
<td>Corridors, Open Offices, Bathrooms, Toilet rooms, Reception, Lobbies, Shopping</td>
<td>45-55</td>
<td>40</td>
<td>30-40</td>
<td>40</td>
</tr>
<tr>
<td>Kitchen, Shopping, Common Spaces, Dining Halls, Computer Rooms, Workshops</td>
<td>45-55</td>
<td>45</td>
<td>40-50</td>
<td>45</td>
</tr>
</tbody>
</table>
Field Research

Based on the measurements, this thesis examines how design strategies influenced acoustic comforts in campus buildings. To find out the major causes of unwanted sound transmissions, the thesis analyses the visual and written documents provided by the building managers and the architects. Site visit/research was also carried out to investigate other possible causes by mainly studying sound transmission through interior walls. The majority of this work carries out an analysis of building layouts because a well-programmed design is a key point for acoustic comfort within buildings [4].

Analysis of Building Materials

This procedure investigates a range of building materials, particularly interior walls, which are one of the main causes of sound transmission between rooms [17]. This study uses STC (Sound Transmission Class) values in order to analyze the acoustic qualities of materials used in the surveyed buildings. According to USG Acoustical Assemblies [17], the interior wall materials will be rated based on a combination of building materials and system designs.

Limitation

While evaluating room acoustic performance based on the current standards of acoustics (ANSI), there was an uncertainty of the standards itself. The standard mostly mentions only the range of allowable sound levels. In this case, the difference between the variation of the sound levels in each room may affect whether this room is properly insulated in terms of acoustics, although the noise levels in the surveyed room stay within the acceptable range.
In addition, due to limitation of time (this thesis and the entire research process were conducted within one year), this thesis only focuses on interior partition walls, despite the existence of other structural and envelope systems (exterior walls, structural frames, floors, and ceilings) that might influence the acoustic performance of the surveyed rooms. For example, acoustic performance can be better or worse based on different structural frames which can function as sound conductors.
CHAPTER 3. RESULT AND DISCUSSION

Indoor Ambient Noise

The purpose of this measurement was to ascertain whether the proposed space has appropriate sound levels that keep the ambient noise as low as possible so that normal speech (from a lecturer) or other special sounds (musical performances) are easily understood and not distracting. Thus, on-site decibel measurements were taken by a decibel meter. The Measurement was carried out during the school hours from 1:00 pm to 5:00 pm, mostly for the Music Hall and the College of Design. For residential buildings, it was taken both during the school hours and during the weekends to see differences in noise levels between normal school hours and the weekend. All the measurements for this research were compared with ANSI (American National Standard) based on its program difference, which is shown in Table 2.1.

![ISU Music Hall Sound Pressure Level](image)

**Figure 3.1 ISU Music Hall Ambient Noise Level; the graph illustrates the sound levels of existing background noises of each room of the Music Building and shows comparisons with the current standard.**
The ISU Music Hall includes a recital hall, a choral room, band practice rooms, a large public lobby, classrooms, practice rooms, and offices. According to ANSI S12.2 [15], for programs with a music-based purpose, such as a recital hall, a choral room, and a band practice room, appropriate sound levels should stay between 25 and 30 decibels. Classrooms are supposed to stay between 30 and 35 decibels and the lobbies should maintain in a range of 45 to 50 decibels [15]. Measurements were taken in the empty rooms of the selected programmatic spaces. The data was obtained both when the room, next to the surveyed room, is occupied and not occupied. As a result, all the measurements in the Music Hall are slightly higher than the allowable sound levels. However, the Recital Hall performs best with respect to acoustics. The room has the most stable sound level among any of the other rooms in the building. The major issue of this building is its age. The building equipment and services are obsolete. Some practice rooms are portable [see image], and the electric lights in the portable rooms create a buzzing sound because the light fixtures are outdated [see image].

King Pavilion

3rd Floor Landing

Figure 3.2 College of Design Ambient Noise Level at Review Spaces: the graphs illustrate the sound level measurements of the review areas in the ISU design building

At the College of Design, the measurement was carried out in the worst indoor spaces which are review spaces where most verbal communication takes place during school hours.
The design students (the users) picks up as one of the worst strategies in terms of acoustics). ANSI S12.2 establishes 30 to 35 decibels as an acceptable noise level for conference rooms or lecture halls as the review spaces can be classified with that function [15]. As the average noise level is close to 50 dB or above, as shown in Fig 3.2, the ambient noise in the review areas in this building far exceeds the allowable level determined by the standard. The major problem of the review spaces is their location, compounded by a failure of layout design (adjacencies) and lack of effective dividers, such as partition walls. See the detailed description of the layout analysis below.

The intention of the measurements in the residential spaces is to see how / how much the background noise and noise from neighbors are affecting the residents in their private rooms. Iowa State University provides different types of residential spaces: apartment-type rooms and dormitories. In addition, considering that the campus housing has both old and new residential buildings, the measurements for the residential units care particularly about the building types and their construction dates. For this reason, three different residential halls on campus were examined: Frederiksen Court (apartments), Helser Hall (old residential hall), and Geoffroy Hall (new residential hall).

The time of the measurements was also carefully considered. The first measurements were taken on weekdays and weekends in order to see how the private rooms are affected by different time periods (because for living units people are the major sound sources that cause disruptive noise to neighbors and to roommates, this measurement needed to be taken at two different time periods). For the second set of measurements, because of the humidity level (sound levels are usually reduced during the nighttime due to the increased humidity levels
[16], they were also taken at both day and night time to check whether there was a substantial difference in the sound levels.

Figure 3.3 Helser Hall Ambient Noise Level; the graph illustrates the sound level measurement of a bedroom (either a comparison between day and night time or week and weekend).

Helser Hall is one of the oldest residential halls on the ISU campus. Although some of the mechanical services such as fans have been replaced, many of the old service infrastructures are still in use. The building also has problems due to single-glazed windows, and the frames of the windows are not properly sealed which leads both to loss of heat and noise transmission from the outside. [see images] The field measurement of noise levels were taken in an empty private room on the first floor of Helser Hall. A total of four times measurements were taken during the day on a weekday (during school hours) and on a weekday night, and a weekend day and a weekend night.

Helser Hall is the residence that is most affected by its neighbors. Small private and shared rooms are tightly packed, and the hallways are narrow do not allow enough space (gap) between the units facing each other. With these adjacencies, students usually open up their rooms at night and let sound travel freely to other rooms and areas, which led to noise levels at night time exceeding those for daytime noise. See Fig 3.3. A major contributor to
the poor acoustic qualities at the Helser Hall was a renovation, which was being done within the building. For this reason, the ambient noise level was higher during weekdays than weekends although there were many students generating disturbing noise on weekends, as shown in Fig 3.3.

![Graph](image1)

**Figure 3.4 Frederiksen Court Ambient Noise Level in a Bedroom; the graph illustrates the sound level measurement of a bedroom (either a comparison between day and night time or week and weekend).**

Frederiksen Court has apartment-type housing units. In one building there are 30 units, and those units are tightly packed next to each other. One living unit includes a shower, a toilet, a kitchen, a living room, and private bedrooms. The measurement of ambient noise was taken in the empty room of four private bedrooms at Frederiksen Court #61. The condition of the unit was as follows; the three private rooms were occupied during the daytime measurement (from 1 pm to 5 pm (normal school hours); the residents seemed to have classes mostly in the mornings, while at nighttime, the residents were out for work. Because of the humidity difference and the number of people who inhabit the spaces, ambient noise during day is (although it is a minor difference) higher than the noise level collected at night. The first graph at Fig 3.4 represents day and night differences in sound levels. Another measurement was carried out during the daytime on a weekend. The data
from both weekday and weekend were compared with each other. The result was that the
noise level during the weekend was higher because students, the inhabitants, usually cause
more disruptive noise (such as parties) during weekends. Overall, according to ANSI S12.2,
the allowable sound level for bedrooms is supposed to be between 25 and 30 decibels [15],
yet the noise level at Frederiksen Court, rising from 35dBA to 45 dBA, goes far beyond the
limit.

Figure 3.5 Geoffroy Hall Ambient Noise Level; the graph illustrates the sound level
measurement of a bedroom (either a comparison between day and night time or week and
weekend).

Geoffroy Hall is the newest residential hall on the ISU campus. This building allows
more public programs for its residents. Large social gathering spaces, study rooms,
conference rooms, and multi-media rooms are programmed for the students' convenience.
The measurement was taken in the empty space of a shared room. As with the other two
residential rooms, four measurements were completed and compared in the graphs shown
above.

Among the three investigated residential buildings, Geoffroy Hall demonstrated the
best acoustic comfort. Average noise levels peaked at 35 dBA while ANSI establishes 25 to
30 dBA for bedrooms [15], Both measurements were again taken at day and night, and
during the week and a weekend. Unlike other residential rooms, Geoffroy Hall maintained its average sound levels without much difference. The results showed that both noise levels from nighttime and weekends were slightly higher than the daytime and weekdays. Despite this slight difference, the room was more affected by the neighbors or residents who were living next to the surveyed room rather than by the room itself.

**Spatial Configuration/Layout**

A common strategy which an architect uses for acoustic design is the layout of a building [4]. Separating public and private spaces and creating additional space between larger programs to avoid sound travel and prevent users from interruption by existing noises is one major strategy. Hence, this analysis investigates how the layout strategies of the existing buildings are designed in terms of sound transmission.

Figure 3.6 *Music Hall ground level; this diagram illustrates the three divisions within the building [18].*
The former design strategies of the ISU Music Hall is 1. Acoustics, 2. Temperature, 3. Traffic, and 4. Aesthetics [19]. Although aesthetics do not seem to be considered, with respect to acoustics the music building works better than any other campus buildings that were built during the same timeframe. One of the major contributors to its acoustic performance is the layout of the building. The ISU Music Hall is, in fact, three separate buildings (one recital hall, one band room, and opera room section, and one section for classrooms and offices) connected only with metal strips (to hide the joints), and this separation strategy ensures a strong sound-proof design [19]. Mechanical Services are located in the basement (with the exception of the light ballasts, which are located on the roof), and ducts are placed at the perimeter of the building [19].

Figure 3.7 College of Design 2nd level: shows the service areas (red), the classrooms (blue), and review spaces affected by noise.

The College of Design has a large atrium area on the first floor which stretches all the way to the roof of the building. Most public programs such as a large lecture hall, a gallery, and the main office are situated on the first floor. Studio spaces, classrooms, and staff offices start from the second floor and continue to the fifth floor. Since the atrium space is open to the roof, studios and offices seem to wrap around this large open space. The Design building attempts to divide public and private programs, but while staff offices are kept well protected from noise, some of the classrooms are extremely noisy because the studio spaces are located
right next to the classrooms. Another problem of the Design building is the open studios, open review spaces, and a large open-to-below space. Studio sections are divided solely by partition walls or desks, and not by acoustic partitions. Review spaces, except the gallery, are wide open. The intention of this openness may be to allow people to freely see the students’ at work; yet, in fact, this space becomes hectic while a review is held because of people walking around the review.

Figure 3.8 Helser Hall 3rd level: shows both service areas (red), and private units affected by the services (blue). Despite its age, the layout of service programs and units appears more organized than in Geoffroy Hall [20].
Figure 3.9 Frederiksen Court 2nd level: In one unit, there is a shared living room, a kitchen, a bathroom, and a built-in washer and dryer. Private/Occupied rooms are exposed to noise caused by the equipment [21].

Usually, residential buildings have fewer possibilities in layout variations. The buildings are more compact with their small individual units. Unlike educational or theater buildings that contain many public programs, these buildings limit public programs to prevent disturbances and to secure the living units. Dormitories like Geoffroy Hall and Helser Hall do involve public programs, but most of these programs are clustered on the first floor. One good thing about dormitories is that these buildings separate restroom, shower, and kitchen from individual units. Although it is inconvenient to walk out of a room and go to a restroom, with respect to acoustics dormitory-type buildings work better than apartments (still, private units that are situated around the kitchen or restroom areas can be disrupted by noise). On the other hand, apartment type housings such as Frederiksen Court are suffering both from neighbors and from the noise caused by the kitchen, restroom, and built-in washer and dryer.
Another strategy that an architect often uses for better acoustic performance is to carefully choose building materials for wall assembly, glazing, and doors. This part of the paper will go through the materials of the surveyed buildings and evaluate them with USG Acoustical Assemblies, which establishes guidelines for STC rates (Sound Transmission Class), “the measurement of the ability of a wall or floor assembly to isolate airborne sound and prevent it from passing from one side to the other” [17].

Figure 3.10 Geoffroy Hall 2nd level: shows both service areas (red) and private units affected by the services (blue) [22].

### Building Materials: Interior Partitions

Table 3.1 [Guidelines of STC ratings for each program of the surveyed buildings][17]

<table>
<thead>
<tr>
<th>Building Types</th>
<th>Program</th>
<th>Minimum</th>
<th>Medium</th>
<th>High</th>
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<tbody>
<tr>
<td>Educational</td>
<td>Classroom</td>
<td>45</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Conference Room</td>
<td>40</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>Theater</td>
<td>Music Room</td>
<td>55</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Residential</td>
<td>Bedroom</td>
<td>45</td>
<td>50</td>
<td>55</td>
</tr>
</tbody>
</table>

Another strategy that an architect often uses for better acoustic performance is to carefully choose building materials for wall assembly, glazing, and doors. This part of the paper will go through the materials of the surveyed buildings and evaluate them with USG Acoustical Assemblies, which establishes guidelines for STC rates (Sound Transmission Class), “the measurement of the ability of a wall or floor assembly to isolate airborne sound and prevent it from passing from one side to the other” [17].
The building materials are compared and examined by USG Acoustical Assemblies, which guides designers to enhance acoustical qualities and provides information about USG products and systems to meet the acoustical requirement. Wall, floor/ceilings, and structural frames are required to meet minimum STC values. STC varies by different building types and by different programs in the building. As the required STC numbers are higher, wall systems or floor systems absorb more sound and allow less sound transmission to other rooms [17]. In particular, higher STC rates are required for service and public areas such as kitchens, bathroom, lobbies, and conference rooms because those rooms involve more sound sources that can cause distracting sounds [17].

Table 3.2  Comparison of Interior Wall Assembles / Materials for Acoustic Performance

<table>
<thead>
<tr>
<th>Building</th>
<th>Thickness</th>
<th>Frame / Structure</th>
<th>Double Layers</th>
<th>Staggered Structure</th>
<th>Acoustic Insulation</th>
<th>Cavity</th>
<th>Acoustic Sealant</th>
<th>STC (supposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helser Hall</td>
<td>Metal</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>44 – 49</td>
</tr>
<tr>
<td>Frederiksen Court</td>
<td>4 3/4&quot;</td>
<td>Wood</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>7 1/4&quot;</td>
<td>Wood</td>
<td></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>55 - 57</td>
</tr>
<tr>
<td>Geoffroy Hall</td>
<td>6”</td>
<td>Metal</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>50, 55</td>
</tr>
<tr>
<td>Music Building</td>
<td>12 1/4&quot;,</td>
<td>Metal</td>
<td></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>19&quot;</td>
<td>Metal</td>
<td></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>?</td>
</tr>
</tbody>
</table>

This thesis focuses on indoor ambient noise generated by indoor sound sources (machines, people, service areas) and on sound travel to other indoor spaces or rooms. The material study investigates specifically interior partition walls, which are one of the main contributors to preventing sound transmission between rooms. Each individual piece of interior walls from the three occupational types and their assemblies will be analyzed based on the guidelines from USG Acoustical Assemblies. Unlike the former analysis of both ambient noise data and of layout, this analysis had limitations due to the old documents provided by the architects. Helser Hall, Music Hall, and Design buildings are all from the 50s.
and 70s, which means their documents are difficult to analyze due to the faded wall sections and the lists of materials for the walls.

In general, music rooms require efficient assemblies to reduce sound transmission as much as possible. However, the ISU Music Hall maximizes the capability of controlling

Figure 3.11 Interior Wall Section Details of the Surveyed Buildings [18], [21], [22].
sound by its materials and assemblies. According to the documents provided by Durant Architects Inc., the Music Hall had multiple variations in its assembly in order to accommodate a varied acoustic environment for both educational and music programs (ISU Music Hall is both a music and educational type building). In the ISU Music Hall, the efficient sound insulating systems are afforded by the double layer structures, the use of concrete block, thickness of walls, and cavities between the assemblies [1], [17]. Classrooms and practice rooms share a similar wall assembly with a thickness of 12”. Interior walls are composed of double layers of gypsum board, 1/8” veneer plaster on 1/2” gypsum board on 1/2” resilient channels, and 1/2” sound insulation batts. In addition, music-based use the thickest type of wall with an 18” thickness [18]. It also employs a double-layer strategy for its assembly. Specifically, this wall assembles double layers of solid concrete blocks with a 2” gap between the blocks [18]. This cavity allows the blocks not to be in contact with each other so that any sound/noise would not travel through the materials. For STC values, according to the Catalog of STC and ICC Ratings, 50 STC is recommended for classroom areas and 55 is the desired maximum [23]. Because the classrooms also engage in music-related activities, the interior partition in the classroom is rated at approximately 58 STC, which is higher than the maximum. Unfortunately, the partition type music room walls are not listed in either USG Acoustic Assemblies, nor the Catalog of STC and ICC Ratings. Thus, I was unable to obtain STC value for this wall.

The College of Design, with its educational purpose, is a studio type building that allows more open plan design to promote communication between students and faculty. Therefore, most review and studio spaces are wide open, which makes an acoustic material study difficult for this particular building.
Residential buildings are more concerned with material issues since they represent fewer opportunities regarding spatial qualities. The spatial challenges are very limited; therefore, an acoustic materials study is highly recommended for this occupational type.

Geoffroy Hall provides a precise description for an acoustic performance of its structural assemblies. The design has proven that acoustic comfort was one of the designers' major considerations. The given documents state STC rates for each assembly and illustrate details of the composed materials. As shown in Fig 3.11, the interior partitions (between two units) is rated at around 50 to 55 for STC while the standard STC rate for bedrooms [22], according to USG, is at a minimum 45, a medium of 50, and a maximum of 55 [17]. The assembly of the interior wall and the material qualities are of high quality in terms of acoustics. The wall assembly employs double layers of gypsum board, staggered metal studs, and acoustical batt insulation [22], which are major contributors for high STC values [1]. These material strategies contributed to the successful acoustic comfort in Geoffroy Hall.

Because Frederiksen Court is an apartment type residence, two types of interior walls were investigated in this section: a partition wall between bedrooms and another one between units. This residential building uses mostly wooded frames for its structure because it does not require a steel structure, which holds more load, due to the limited number of floors (three floors). Because it uses a wooden frame, this results in a profound difference in acoustic insulation. The STC value is as low as 37 in this case. USG Acoustic Assembly establishes 45 STC as a minimum for bedrooms [17], and the interior walls in bedrooms at Frederiksen Court offer much lower values than the minimum. The STC value of a different interior wall system, between units, ranges approximately from 55 to 57, which is a maximum for bedrooms. This assembly uses a staggered structure and allows air space
within the wall [21]. Despite its use of a wooden frame, the assembly method led to a
dramatic improvement in acoustic control. In the case of Frederiksen Court, the USG
standards did not state the condition of the interior wall, shared by units and again by the
bedrooms of the units.

Unfortunately, for Helser Hall, its blueprint only provides one section for exterior walls.
For interior walls, it only leaves a short note about the materials of the interior wall assembly.
According to the provided document, the interior walls of Helser Hall are composed of 5/8”
gypsum drywall with 3-5/8” 25-gauge steel studs 24” o.c. with acoustic batt insulation filling
in the cavity [20]. The structure is similar to one of the exemplary structures in the USG
assembly standard. Thus, the STC rate is assumed to be approximately 45 to 49.
CHAPTER 4. CONCLUSION

The result of the study revealed that the difference in occupational types affected the design strategies of each building and resulted in a varied acoustic environment. Despite its old construction date, the ISU Music Hall, which is a theater type building, had a better acoustic performance among any of the other buildings, namely the College of Design (educational), Frederiksen Court, and Helser Hall (residential), with the exception of Geoffroy Hall, which is the newest building on campus. Beyond that, the physical measurements proved that the surveyed buildings often do not meet acoustic performance standards (ANSI or ISO) because of its inefficient architectural designs in layout and the use of materials.

ISU Music Hall was proven to establish the best control over acoustics for its students. The material and its layout strategies were better than any other programs on the ISU campus. However, the building still had some problems with its classroom areas. Some of the classrooms were located adjacent to practice rooms that became very loud when students were practicing their instruments, causing acoustic discomfort in the rooms next door.

The main design problem for the College of Design was found in the locations of the review spaces. Most of the review spaces were located in busy circulation zones (for example, next to stairs, elevators, the large atrium, and a place between fire stairs and restrooms). Because of their locations and lack of partitions, the presentations and other events were extremely affected by many types of indoor noise (people, machines, services, and so on). The careless design continues to be detrimental to the learning and communicating environment and the students, staff, and faculty in the spaces.
The three residential buildings with three different time periods demonstrated a transition of the development in acoustic design. Helser Hall, the oldest residence on the ISU campus, had the worst scenario for acoustic design. Although this building exhibits a fairly good layout strategy and it uses similar interior assemblies as other residential buildings, the quality of materials was so old and outdated that the interior walls no longer prevented noise transfer. On the other hand, Geoffroy Hall, the newest building, had the lowest ambient noise level. Its material and spatial qualities allowed the units to maintain the best acoustic environment for its residents.

The findings of this study reveal a failure of architectural design in acoustics at all three occupational building types on the Iowa State University campus. This thesis suggests a remedy of intervention and renovation for some of the buildings surveyed for this study. The renovation is not only limited to the investigated buildings but also includes other buildings that do not follow the standards. In particular, acoustic comforts in educational and residential buildings are often overlooked compared with performance-focused spaces such as music buildings, whereas students spend most of their time in either educational and residential buildings. If the acoustic comfort is not guaranteed, this will cause increased stress, impaired learning activity, and other health-related damages from the young occupants.
REFERENCES


