Logistical Planning and Cost Estimation for a Student-Based Live Streaming Studio at WPI

An Interactive Qualifying Project Report
submitted to the faculty of
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Table of Contents

List of Figures

Abstract

The purpose of this project was to fully research and propose a live streaming studio with a budget of $75,000. The live streaming studio was meant as a lab to help teach students by allowing them to work with all aspects of a live streaming studio. The audio, video, and software components of the livestream were each carefully researched and a proposed design for the studio was developed. This report details and outlines the research, consideration, and ultimate decision on how this studio should be constructed.

Executive Summary

The goal of the project was to design the technical aspects of a live streaming studio, from the ground up, in WPI, so that the students may use it to experiment with live video production. The total budget to accomplish this is estimated to be $75,000. To do this, the studio was split into several sections: acoustics, audio, software, video, computing & encoding, and lighting & other.

While researching each of these sections, certain recent technological advancements were identified as targets for the live streaming studio. For example, quadratic residue diffusers use concave surfaces to diffuse sound evenly around the room, and BNC cables, which were created to be durable in order to deliver electronic information reliably.

To make use of these discoveries, proposed designs for the technical aspects of the studio, which is 15 feet by 10 feet in surface area, had to account for everything interconnecting with each other. The proposed video camera, the Blackmagic Design Picket Cinema 4K, could livestream video in up to 4K, meaning that if the studio wanted to be capable of live streaming in 4K, all of the components that handled video transmission had to be capable of live streaming in 4K as well. The reverse is also true: If the camera was the only thing that could live stream in 4K, it could be replaced with a cheaper camera that would only move up to HD. The other components followed suit, and a hypothetical list of components in the studio was made.

In order to prove the viability of the components, a proof of concept was made involving the audio input, the HD video input, and the livestreaming software, vMix. After discovering some input issues and camera faults, the proof of concept could receive both the audio and video and encode it in HD, making it ready to be livestreamed. While not proving everything, it showed that the logic behind out methodology was sound.

After all the above, the total cost of each section was added up, and resulted in the proposed technical aspects of the room totaling up to be $18,497.44, well below the initial budget of ~$75,000, but not taking into account outside costs such as labor:

Section	Name	Price
Acoustics	Acoustic Treatment	$5,320.00
Audio	Audio Equipment	$3,370.00
Audio	Audio Cables	$370.00
Software	Ableton Live	$450.00
Software	Lightjams	$125.00
Software	vMix 4K	$700.00
Software	Vimeo Advanced+	$780.00
Video	Video Transmission	$4,720.82
Lighting & Other	Light Rack and UPS	$647.00
Encoding	Streaming Computer	$2,014.62
	Total:	$18,497.44

Table A: Total Technical Cost of the Live Streaming Studio.

Background

The Concept of Livestreaming

Although the concept of a "live stream" may seem hip and modern, live streaming existed as early as 1890, when the French Théâtrophone service used telephone lines to broadcast live performances of theater and opera to its paying subscribers. The service continued broadcasting music and intermittent news updates until 1932, when the mainstream adoption of the radio and phonograph rendered it obsolete. A similar service called Muzak operated in America from 1934 to 1981, which streamed music into elevators and workplaces. Another service, the Telephone Music Service, allowed patrons of bars in Pittsburgh to send music requests to an operator though special jukebox telephones from 1929 to 1997. The revenue from the jukeboxes was shared between the music service and the tavern owners. (Wikipedia Contributors, 2022)

Throughout the later 20th century, the invention of computer networks allowed users to communicate across the globe. Powerful home computers, advanced internet infrastructure, and novel data compression techniques eventually supported the bandwidths required for live transmission and playback of video and audio. The first band to ever perform live over the internet was Severe Tire Damage on June 24, 1993. Their performance in Palo Alto, California was watchable as far away as Australia. Although the quality of the live stream was poor by today's standards (only 152x76 pixels), this was an impressive feat at the time. (Wikipedia Contributors, 2022)

Over the next decade the internet became faster and increasingly commercialized. Live streamed internet broadcasts became increasingly common. RealAudio Player was one of the first media player software capable of streaming over the internet, and it was used by ESPN to stream the first live internet broadcast of an MLB game in 1995. In 1999 Bill Clinton participated in the first presidential webcast. (Wikipedia Contributors, 2022)

In the modern day, live streaming has become ubiquitous. Anyone with a smartphone and a decent internet connection can easily start a live stream in a matter of seconds. Platforms such as Youtube, Twitch, Facebook, and Vimeo provide convenient platforms for users seeking to distribute their content to hundreds, thousands, or even millions of viewers. For some people, live streaming has become a full-time career. Revenue can come from a number of sources including advertisers, merchandise, affiliate programs, and donations directly from viewers (Bybyk, 2022). From musical performances to esports, live streaming is an industry on the rise.

Room Acoustics

The first step in planning a live streaming studio is making sure the sound quality is the best it can be. A poorly planned room can ruin the quality of even the best musical performances. This section describes the basic principles of acoustic treatment and design, which will later be applied to the design of the livestreaming studio at WPI. For simplicity, assume all of the information in this section is cited from Everest and Pohlmann (2021) (except for the parts that are specifically cited from elsewhere). We assume the reader already has a basic concept of sounds as waves with frequencies and amplitudes.

“Reverberation” is a familiar and immediately noticeable acoustic property of any room. A reverberant room may add a bright, spacious quality to music, but it will also blur notes and syllables together, making speech difficult to understand. Inversely, if a room is not reverberant enough it may sound dry or “dead”. Reverberation can be quantified using what is known as the RT_{60} value (also called the “reverberation time”), defined as the amount of time for sound energy in a room to decay by 60 dB. A room covered in acoustically reflective surfaces such as hardwood tables or ceramic tiling will have a higher RT_{60} and will therefore sound more spacious compared to a room with a lot of absorptive surfaces such as carpeting and drapery.

To further complicate things, different frequencies of sound decay at different rates – some surfaces are excellent at absorbing lower frequencies while others only absorb higher frequencies. All surfaces can be characterized by an absorption coefficient (ɑ), which ranges from 0 to 1 and describes how much sound energy the surface absorbs per unit of area. An open window, for example, will have an absorption coefficient of 1.0 because no sound is reflected back. Retailers of acoustic paneling usually provide data sheets listing their material’s absorption coefficients at a few standard frequency bands. Some brands even advertise coefficients greater than 1.0, but this is due to a technicality in the way the values are measured. When doing calculations, the coefficients should be rounded down to 1.0 whenever this happens.

The Sabine Equation, devised in the 1890s by Wallace Clement Sabine, is a widely used equation for estimating the value of RT_{60} given the absorptivity of a room at a particular frequency:

$$RT_{60} = \frac{0.049V}{A}$$

Where V is the volume of the room in cubic feet, and A is the total absorption of the room measured in units of sabins. The total absorption A can be calculated by adding together the surface areas of everything in the room multiplied by their absorption coefficients. 1 square foot of material with ɑ=1.0 will contribute 1 sabin of absorption. For reference, a typical college student will provide about 5.0 sabins at frequencies above 1000 Hz but only about 2.5 sabins at 250 Hz.

Recording spaces will often have absorptive paneling mounted on the walls to absorb middle and high-range frequencies. Spacing absorbing panels apart from each other and mounting them slightly away from the wall can make them more effective by increasing their exposed surface area. For peak efficiency, the absorbers should be placed ¼ wavelength away from the wall, which is where air particles will have the greatest velocity (though a 2-inch gap is usually wide enough). Low frequencies are reduced using special absorbers called “porous bass traps”, which often look like wedges placed along the coroners of the room where low frequency energy tends to gather (Sweetwater, 2022). Additionally, mounting the panels in a way that makes them easy to rearrange and remove can allow users of the room to tailor the absorptivity of the room to their liking, creating a more versatile recording space.

The next part of acoustic design to consider are standing waves. When a sound wave hits one or more walls, it is reflected in a new direction. The reflected sound is then “stacked” on top of the original wave. If the two waves are out of phase, they cancel out. However, if they are in phase they combine into a more powerful wave in a process called constructive interference. Certain frequencies of sound in a room will combine constructively multiple times and form standing waves that appear to oscillate in a single area. Standing waves are a huge problem in acoustics because they can significantly increase or decrease the intensity of specific frequencies, depending on where a listener is positioned. These frequencies are known as room modes, and they are unique to the geometry of a room. Large auditoriums will have modes at lower frequencies than small recording studios. In a six-sided box-shaped room there are three kinds of modes: axial, tangential, and oblique. Axial modes are the strongest modes and result from sound reflecting off of a pair of two opposite-facing walls. Tangential modes are the result of sound reflecting off of two pairs of opposite walls and are typically 3 dB weaker than axial modes. Oblique modes are the weakest (6 dB below axial) and result from reflections on all three pairs of walls. These three types are illustrated in Figure 1.1:

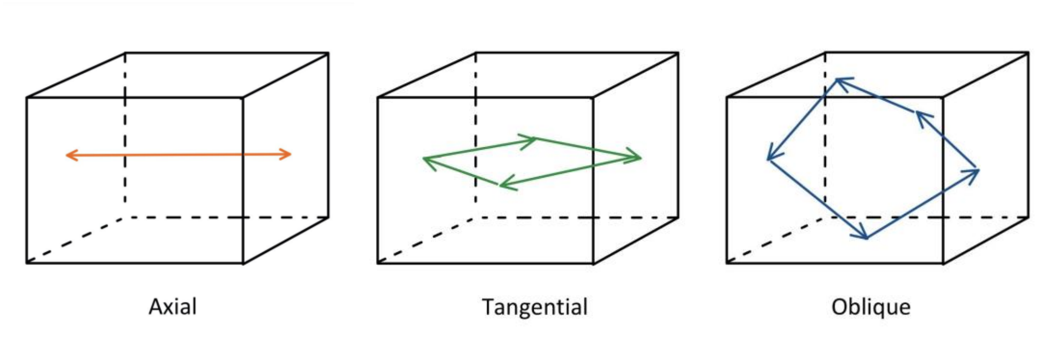

Figure 1.1: Types of Room Modes.

The mode frequencies for a box shaped room can be easily calculated using the following formula:

$$Frequency = \frac{c}{2}\sqrt{\frac{p^2}{L^2} + \frac{q^2}{W^2} + \frac{r^2}{H^2}}$$

Where c is the speed of sound (1,130 ft/sec), L W H are the room's dimensions, and p q r are all integers greater than or equal to 0. A computer program can very quickly compute all possible room modes within a given frequency band. It is worth mentioning that altering a room to have a non-cubic shape will not remove standing waves. Instead, it will shift them around and make them more complicated to predict.

At high frequencies, there are so many modes that they blend together and become unnoticeable. However at lower frequencies, room modes are spaced out and can create audible defects in the sound. To reduce the severity of this problem, specialized absorbers called *resonating bass traps* are tuned to selectively absorb specific frequencies (Sweetwater, 2022). Resonating bass traps have been used by humans for a very long time; Medieval churches in Scandinavia have been found with hollow pots embedded in the walls that are thought to have served as early *Helmholtz resonators*. A Helmholtz resonator (HR) is a simple resonating bass trap that consists of an air cavity with one or more openings. The sizes of the openings and the volume of the cavity determine the frequency the resonator will absorb, similar to how a glass bottle will produce a characteristic sound when air is blown across the top. A fibrous material stuffed inside the cavity creates air resistance that converts the vibrational sound energy into heat energy, dampening the sound. The shape of a resonator can be whatever is most convenient in terms of construction or aesthetics.

Another type of resonating absorber is the perforated panel absorber (PPA). These are panels covered in small holes that are mounted onto a wall. The air between the panel and the wall form what are essentially many small helmholtz resonators. Fibrous material can sometimes be inserted between the panel and the wall to broaden the frequency range of the absorber. PPAs are very easy to construct, but they usually do not go much lower than 90 Hz (Foley, 2013).

The next acoustic property worth considering is *diffusion*. Diffusion is the process of scattering reflected sound so that it is evenly spread around the room. In an ideal, perfectly diffuse sound field, reverberation time and sound intensity would be the same no matter where a listener is positioned. Additionally, a diffuse sound field will have a perfectly exponential decay, free from irregularities and fluttering effects, which occur when sound interferes with its own reflection. Although perfect diffusion is not possible in the real world, incorporating diffusive elements into a room’s design can still improve its acoustic quality. This is done using reflective surfaces with geometries that scatter reflected sound. Something as simple as a wooden cylinder would make an excellent diffuser, but more sophisticated solutions also exist. Manfred R. Shroeder developed a special kind of diffusive element called a quadratic residue diffuser (QRD). These diffusers have grooves carved into them at various depths based on a mathematical sequence to optimize scattering across a wide range of frequencies. The same type of sequences can be used in two dimensions to scatter sound vertically as well as horizontally. A well-designed studio room should have diffusive elements on all pairs of opposing walls.

Finally, acoustic treatment must account for *external* sources of noise. External noise might originate from ventilation systems, a busy road, or even the footsteps of people walking around upstairs. If someone sneezes in another room, it should not be audible in a recording. Realistically, external noise can never be prevented entirely, but with proper planning and treatment it can be significantly reduced. A brief exploration of potential soundproofing options is included in the Methodology section, but this is a complex topic that is best left for more thorough analysis.

Software and Computer Hardware

The organization and output of the video and audio is the central pillar to the success of any live streaming studio, as making sure the distributor of the livestream has the correct format and amount of information is crucial. Before anything else, making sure that all cameras, microphones, and other inputs can be encoded in a livestream software is vital, as encoding compresses the data gathered from the inputs and sends the more manageable amount of data to the livestream distributor in a format that can be accessed by any user device. (Live Stream Encoding, n.d.) Compressing data breaks down the raw feed from the cameras and microphones into smaller bits of data that can be processed and sent out faster than the raw feed. Encoding is vital to any good livestream software, and well known software such as OBS, vMix, and Livestream Studio 6 have encoding built into them.

As for hardware, computers with not only high processing power but also a high number of ports for USB, HDMI, and possibly even BNC ports are wanted, as it would need to be capable of handling uncompressed video footage from every camera one chooses to livestream with. The computer would also need to be capable of connection to a video switch, a device that can take the inputs from the cameras, livestream software, and any additional media, and allows the user to choose which camera and/or graphic to encode in the livestream software. It can be a physical device that can rest in the control room, but recently some software such has vMix has made it possible for the video switch to be all digital, reducing the amount of space taken up in the control room.

Audio Equipment

It goes without saying that microphones are necessary to record and stream audio. Although many cameras come with built-in microphones, these cannot be repositioned without moving the entire camera. For top-quality audio and recording flexibility, a studio needs several dedicated microphones. There are so many kinds of microphones that choosing the right ones can be a daunting task. Thankfully, most modern microphones fall into one of two categories: *dynamic* and *condenser* microphones. Dynamic microphones operate by using sound energy to vibrate a conductive coil. As the coil vibrates, it passes near magnets that produce a detectable electric signal. Dynamic microphones tend to be very durable and can register louder and lower-frequency sounds than condenser microphones, making them well-suited for instruments like drums. Condenser microphones contain a diaphragm made out of conductive plates. When sound hits the diaphragm, the capacitance between the plates changes in a way that can be measured by an electric circuit and converted into a signal. Unlike diaphragm mics, condensers must be supplied with 48 volts of “phantom power” in order to function. Fortunately, almost all modern audio interfaces support this. The diaphragms of condenser mics come in various sizes, where smaller diaphragms are better for higher-frequencies and larger diaphragms are better for lower-frequencies. These microphones are more fragile than dynamic mics, but they can also register quieter sounds, making them well-suited for recording speech. (Wreglesworth, 2022)

There are also other properties that affect how a microphone sounds. Some microphones are designed to record sound coming from all directions (“omnidirectional”), while others are made to only listen in a narrow direction (“cardioid”). (Wreglesworth, 2022) Some microphones can even switch between multiple polar patterns with an onboard switch. Different microphones have their own strengths and weaknesses, so it would be useful to have several different microphones in a studio for an audio technician to select from.

For certain situations, it may be necessary to connect many microphones into one computer simultaneously. An audio interface is a piece of hardware that allows many microphones and speakers to plug into a single computer at once. The device “interfaces” between the digital signals used by the computer and the analog signals used by the microphones and speakers in a way that preserves as much sound quality as possible (E-Home Recording Studio, 2022). Interfaces usually plug into a computer through a single USB port, but there are also products that use thunderbolt or ethernet connections. Knobs on some interfaces allow audio technicians to easily adjust the signal gain of each input and output, and preamplifiers built into an interface can boost incoming microphone signals before processing, resulting in a cleaner sound. Audio interfaces also supply the “phantom power” that condenser microphones need to function. There are many different audio interfaces available, so it is important to know the number and type of connections that are needed. Smaller, less-expensive interfaces might only provide two analog inputs and outputs, while the larger rack-mounted interfaces can support 20 or more. (Sweetwater, 2020)

An audio interface should not be confused with an audio mixer, which combines many inputs into a single stereo input track. If someone wanted to isolate or remove an instrument after recording using an audio mixer, they would be unable to do so. Audio interfaces do not combine signals. Each input goes into its own track in whatever software is used by the computer, allowing for much more flexibility in a studio environment. Some mixers do support multichannel recording as well, but a regular interface is the simpler and more cost-effective option for our purposes (Sweetwater, 2020).

Finally, a studio needs at least one pair of studio monitors. Similar to home speakers, studio monitors are used for audio playback. The difference is that home speakers will often amplify certain frequency ranges to enhance the listening experience, which is not favorable in a studio environment. Studio monitors are designed to render sounds as accurately as possible so that any imperfections or imbalances in the sound will not go unnoticed (Neumann, n.d.). Some modern studio monitors also provide additional features such as the ability to adjust the speaker's frequency response to better suit its acoustic environment.

Cameras

Professional video cameras are one of the few parts of broadcasting and recording that evolves much faster and more efficiently than other parts of broadcasting or live streaming. For example: In 1997, Sony released the HDW-700, the first video camera capable with HD recording and broadcasting in 1920 by 1080, previously only limited to movie production. Ten years later, in 2007, Dalsa debuted the Dalsa Origin II, the first 4K production camera for film, and was produced for commercial use. (Camera Profile, 2014) The speed at which improvements are made to professional video cameras is significant compared to the speed and increase in quality compared to other aspects of live streaming, and this should be taken into account when deciding on video cameras for the live streaming studio.

For any live streaming camera that is purchased for the studio, there are a few requirements that traditionally lead to consistent success. The first thing is the ability to transmit live HD (1920 by 1080) video to the computer the livestream software is on. Higher resolutions give more room for flexibility and would be favored, but the bare minimum for a capable live streaming studio is high-definition video. The second is being versatile, as cameras that are capable of doing more than one thing have a longer utility window than those that only do one thing really well. Cameras that have interchangeable lenses for close shots, portrait shots. and wide shots have a much higher value than a camera that can only do portrait shots. In addition, the size of the camera has also contributed to its longevity. Larger cameras that take up more space often leave less room for other parts of a broadcast or livestream, while smaller cameras allow for more positions and angles. As a trade-off for its smaller size, these cameras have traditionally given up performance and versatility to do so, but due to the rate at which video camera improvements have been made, cameras of similar performance have gotten smaller over time.

Lighting

Since lighting could refer to anything as early as the first torches being made, the lighting that this background section will cover will be in relation to cinema production. More recently, new types of cheap, efficient lighting sources called “ring lights” have made their way into mainstream culture for being cheap and available to common people who may not have the knowledge of how to properly use or have space to place advanced lighting fixtures. On the professional side, as motors and microprocessors continue to get smaller and smaller, lighting equipment has gained the ability to move to pre-programmed positions at the push of a button. This is appropriately called “programmable lighting”, and it allows for more dynamic lighting during live streaming by removing the need for a lighting worker to manually move the light each time a person moves on stage. This is particularly good for large stages with significant room, as it allows for more grand light shows behind the performers. The key, in this case, is to find a good balance between the affordability of the ring light and the functionality and performance of programmable lighting.

Cables

Even as camera, audio, and digital technology has improved year over year, the way that information moves has had to change very little, and thus many different types of cables are available for every department as necessary. The XLR cable, or the “X” series latching “L” cable with a synthetic rubber “R” compound, is a variant of the original type O connector. The XLR cables were manufactured at a high level as early as 1955 and is still one of the main cables that transfers audio inputs to audio interfaces (Rouse, 2022). The main types of audio cables that we will be using are the aforementioned XLR cable, the TRS (Tip, Ring, Sleeve) cable, and the TS (Tip, Sleeve) cable. The TRS is used for refined and unrefined audio and can carry multiple audio signals, while TS can only do one track on an unrefined signal. These two are frequently used to carry unrefined audio inputs from instruments and devices that are not typically used to record audio, and do not have the space or development to house a whole audio system.

Regarding camera cables, the two major and most commonly used cables for transferring live video feed are BNC cables and HDMI cables. BNC cables, or “Bayonet Neill-Concelman” connectors, were designed in the early 1940’s, with the purpose being to quickly connect analog composite video as well as digital video to other devices, being developed for military use initially, before seeing more use as an accessible way to transmit video for people who did not have the means to more expensive or slower ways to transmit video. (BNC Connectors, n. d.) The largest challenge with camera related cables, however, is that the signal from the cables needs to be converted to a different cable type, USB, to be read as an input by a standard desktop computer. USB, or Universal Serial Bus, are standardized types of cables that are the most common when one is looking to provide an input to a central computer. Recently, USB-C is becoming the preferred option when looking at USB types due to transmitting faster than previous types, but USB A, B, and C are all viable options at this point in time.

Methodology

The purpose of this project is to find a way to completely build and furnish this live streaming studio while staying under a $75,000 budget. Again, since this would be the only money to work with, this would be the primary limiting factor. We also have to test to see if the situation that we talked about actually happens or if something different happens entirely. This will be most helpful evaluating similar situations in the studio.

Room Acoustics Calculations

In order to properly plan the acoustic treatment of a room, we need to know the exact dimensions of the space we are working with. In this case, each room is 10x15x10 feet, and they share a long wall. As mentioned, we will refer to the in which recording takes place as the "studio room", and the other room as the "control room".

We begin by finding the amount of absorptive material the studio room will need for optimal reverberation time. Different use cases warrant different reverberation times – music tends to benefit from slightly more reverberation than speech. Everest and Pohlmann (2021) suggest a music and speech "compromise region" for rooms with a volume of 1,500 ft^3 between approximately 0.3 and 0.6 seconds (p. 457). Based on this, 0.45 seconds is a reasonable target. The Sabine equation is used to solve for total absorption. Ignoring the absorption of the walls and floor, we find that we need *160 sabins* of absorption. Commercial acoustic panels often have absorptive coefficients of at least 1.0 for high-frequency ranges, so we will need roughly 160 ft^2 of acoustic paneling. The word "roughly" is used because certain factors will increase the absorption. For example, mounting the panels so that they are spaced a few inches from the wall will increase their effective absorptive area. Also, this number does not account for any furniture, carpeting, or people in the room, which will increase the absorption further. This is why removable paneling is important. An audio technician can measure the room absorption using specialized software (discussed in the Results section) and then remove or add absorptive elements as they see fit. A removable floor rug may be preferable to a permanent carpet for the same reason. In the case of recorded audio, appropriate reverb can even be artificially introduced with software. The absorptive panels should be spread around so there is fairly even absorption around the room. Porous bass traps installed in the corners will deal with broad low-frequency absorption.

The control room follows a different design because it serves a different purpose. The goal of the control room is to optimize audio accuracy in just a single listening position. A common way of achieving this is the “live-end dead-end” (LEDE) method, which is detailed by Everest and Pohlmann (2021). For LEDE, all of the absorptive paneling is placed on the side of the room with the speakers and listener (the “dead-end”). The opposite “live” end of the room is treated with reflective diffusers. The goal of the LEDE design is to prevent reflected sound from interfering with what the listener hears without deadening the room too much. There exist more complex designs that further improve the listening quality, such as creating a reflection-free zone using splayed walls, but those are left for future research.

Next, there is sound diffusion. For the case of small studio rooms, Everest and Pohlmann (2021) state that “In practice, it would be difficult to provide too much diffusion” (p. 458). Going off of this advice, all the remaining available wall space should be used for diffusion. It is also important that all pairs of opposing walls should have at least one side with diffusive elements to prevent comb-filter effects, which occur when sound reflections off a pair of walls interfere with each other. These diffusive elements could be 1D or 2D quadratic residue diffusers or even simply large half-cylinders made out of wood. If the diffusers are 1-dimensional, there should be a balance of diffusers arranged horizontally and vertically.

Another issue to tackle is room modes. With such a small space, room modes pose a great threat to acoustic quality. We have already described how resonating bass traps are used to selectively absorb specific low-frequency tones. The goal is to simply match the resonator frequencies with the most problematic room modes. This section proposes the frequencies that should be controlled in order to optimize the frequency response of the room. To analyze and compare all the possible resonator designs would be too time-consuming, and unfortunately must be left for future research.

Using the previous equation, a simple computer program was written to compute and plot the axial, tangential, and oblique modes of the rooms. The resulting plot is displayed as Figure 2.1. The complete python code is provided in Appendix A.

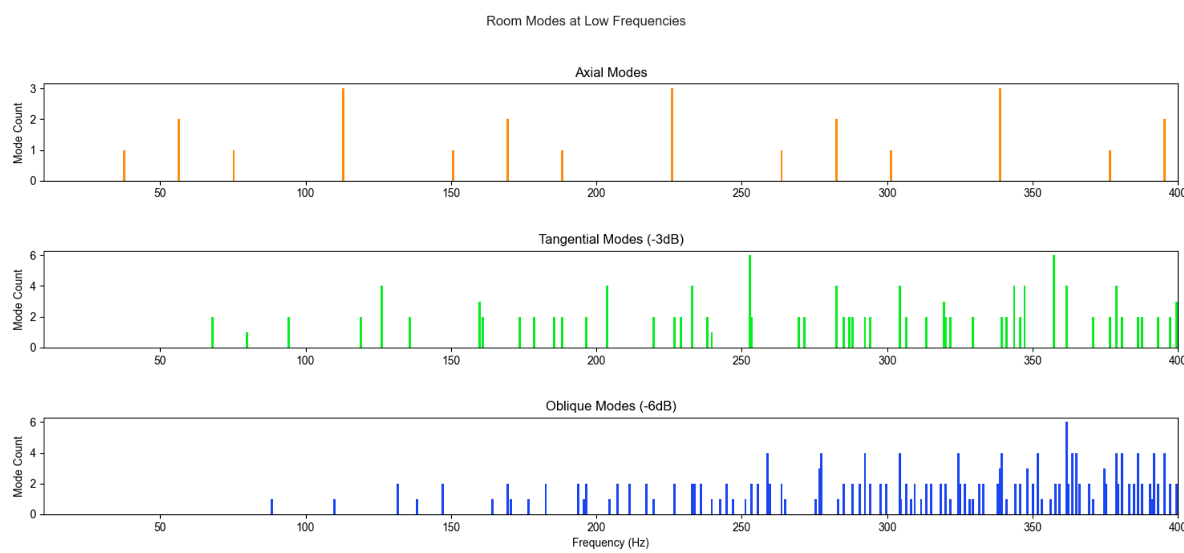

Figure 2.1: Room Modes Plot. Axial, tangential, and oblique room mode frequencies for a 10x15x10 ft room. Frequencies are rounded to 0.1 Hz before finding degeneracy.

As stated in the Introduction, the modes should be evenly spaced with as few degenerate peaks as possible. It is worth mentioning that the room modes of the studio are *far from ideal*, and a room with these dimensions would not be a great candidate for a recording space.

Anyways, axial modes should be dealt with first, as they are the most intense. The peaks in the first plot of Figure 2.1 occur at all multiples of 56.5 Hz, so these should be reduced first. The peaks at multiples of 113 Hz are threefold degenerate, so those frequencies may require more resonators to control. If space allows, there are also some tangential modes that could be controlled such as the peaks at 126 Hz and 252 Hz.

The studio room will also need some form of external soundproofing to reduce unwanted background noise. Everest and Pohlmann (2021) include several chapters detailing this very subject. One soundproofing measure one might expect for such a small-budget recording studio would be soundproof doors designed to create airtight seals when closed. Noisy foot traffic can be reduced by installing floor padding upstairs, in neighboring rooms, and in hallways. Ventilation systems can be quieted by installing turbulence-reducing air ducts and/or isolating the HVAC unit from the rest of the building’s structure using spring mounts. Other measures for noise reduction include altering the wall’s material and support structure, but this is far outside the budget and scope of this paper.

Proposed Room Treatment

An example design for acoustic treatment is provided in Figure 2.2. For a fully rendered 3D interpretation of the design, see Appendix B.

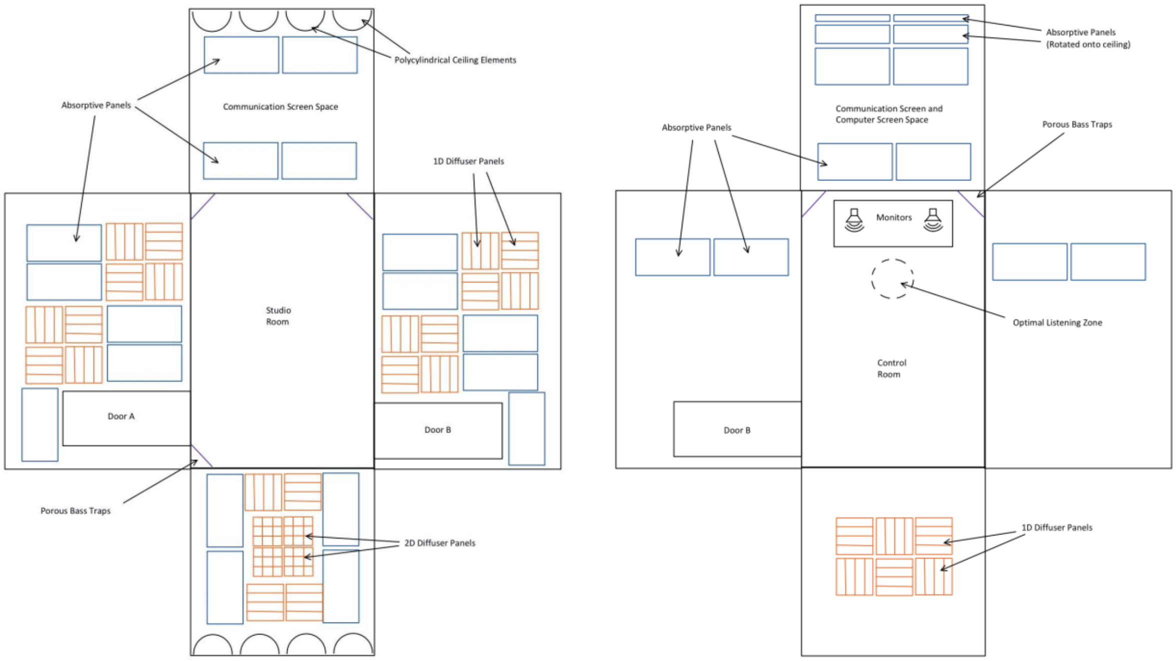

Figure 2.2: Acoustic Designs for the Studio and Control Rooms.

The plan includes porous absorbing panels, porous bass traps, and two kinds of diffusing elements. Additional wall space is provided in each room for a television to facilitate communication between the two rooms while the doors are closed. The studio room contains the recommended 160 square feet of absorptive paneling divided into 2’x4’ panels of 2” thickness. Porous bass traps provide some high-frequency absorption due to their material, so this is counted as well. The wall panels should be mounted with at least a 2” gap from the wall to improve efficiency. The ceiling of the studio room is covered with polycylindrical diffusive surfaces to prevent comb filtering with the floor. These ceiling cylinders are included as an example; differently shaped ceiling panels can provide the same effect. The control room follows the LEDE design with absorptive panels on one side and diffusing panels on the other. The resonating bass traps are not included in the diagram, as their exact dimensions and mounting style are unknown. In any case they should be located near the room’s corners for maximum effectiveness.

From this plan, cost estimation is straightforward: count the number of acoustic elements and multiply them by their unit prices. The cost of the design is summarized in Table 2.1, and the reasoning behind the vendors is described in the following section.

Element	Vendor	Count	Unit Price	Total Price
2ft x 4 ft Absorptive Panels (2” thick)	ATS Acoustics	30	$72	$2,160
1ft x 4ft Porous Bass Traps	Acoustics America	6	$90	$540
2ft x 2ft x 3” 1D Quadratic Residue Diffuser	BXI	26	$70	$1,820
17.5”x17.5”x5.5” 2D Quadratic Residue Diffuser	GIK Acoustics	4	$200	$800
			Total:	$5,320

Table 2.1: Cost Analysis of Acoustic Treatment

The decision between product vendors was decided based on a balance of effectiveness and cost. For the absorptive panels and bass traps, the cost and performance is nearly identical between various vendors, so the decision was based on more arbitrary features such as fire-rating and color options. Cheap acoustic foam is not included because it tends to have poor mid-frequency absorption (leads to an unbalanced frequency response) and is usually not fire rated. In other words, you get what you pay for. ATS Acoustics panels are chosen because of their option to print custom designs on the panels. The studio could be adorned with a decorative pattern, wall-spanning decals, the WPI logo, or something else.

For the diffuser panels, the decision of the vendor was based primarily on the lowest cost. The four 2D QRDs were chosen for aesthetics, and they could be substituted for 1D QRDs if the budget demands it. Similar to the cheap absorptive foam, there exist significantly cheaper diffusive tiles made out of plastic. While inexpensive, these panels tend to be quite small, which limits their ability to effectively diffuse mid and low frequency sounds (*Best Types of Sound Diffusers: Should You Buy or DIY Them?*, 2020). It is worth noting that the diffusive panels are made out of wood, so they could likely be constructed by WPI students for much less than their retail prices. For this option, *Soundsplash* by HX Audio Labs is a convenient free software meant for simulating the effectiveness of QRD designs based on channel depth (Sound Splash, n.d.). The ceiling elements and the resonating bass traps are not included in the price estimation as they would likely need to be custom-built for this room. As with the diffusers, these could also be constructed by WPI students out of wood or a similar material once the design is finalized.

Treating for external sounds will also add to the budget. A soundproof barrier is only as effective as its weakest link. For most acoustic spaces the weakest parts are usually the doors (Everest and Pohlmann, 2021). Special airtight doors will need to be purchased to prevent sound from leaking through. According to Walker (2021), such soundproof doors can cost anywhere from $100 to $400 for a solid wood door, depending on the material and size. Additional costs may include sound treatment for ventilation systems and floor padding to reduce the sounds of foot traffic in nearby rooms. Analysis of these techniques is left for future research. Finally, a tube of soundproofing caulk should be used to seal any air holes in the room's walls, such as those used for microphone and video cables. A tube of caulk only costs about $15 from ATS Acoustics.

Audio Equipment

In terms of audio equipment there are many required devices: microphones, stands, an audio interface, and studio monitors. There are also some optional accessories such as pop filters and shock mounts. The cost breakdown of all the equipment is summarized in Table 2.2. The following paragraphs detail the reasoning behind each product. As with the room design, this list is just one of many possible studio designs, and higher-end alternative products can be substituted if the budget allows. The total cost of audio equipment (excluding cables) comes out to $3,370.

Item	Product Name	Vendor	Count	Unit Price	Total Price
Dynamic Microphone 1	SM57	Shure	4	$100	$400
Dynamic Microphone 2	SM58	Shure	2	$100	$200
Small Diaphragm Condenser Microphone	VMS ML-2	Slate Digital	2	$150	$300
Medium Diaphragm Condenser Microphone	AT2020	Audio Technica	2	$100	$200
Large Diaphragm Condenser Microphone	AT2035	Audio Technica	2	$150	$300
Measurement Microphone	EMM-6	Dayton Audio	1	$80	$80
Shock Mounts	GFW-MIC-4248	Gator Frameworks	2	$25	$50
Tall Mic Stand	MS7701B	On-Stage	6	$40	$240
Short Mic Stand	GWF-MIC-0821	Gator Frameworks	2	$50	$100
Desk Mic Stand	DS7200B	On-Stage	5	$20	$100
Main Audio Interface	Scarlett 18i20	Focusrite	1	$550	$550
Secondary Audio Interface	Scarlett 2i2	Focusrite	1	$180	$180

Studio Monitors	JBL 305P MkII + LSR310S Subwoofer	JBL	1	$570	$570
Studio Monitor Stands	GFWSPKSTMNDSK	Gator Frameworks	1	$100	$100
				Total:	$3,370

Table 2.2: Cost Analysis of Audio Equipment

There needs to be a selection of different microphones to choose from for different use cases – live streaming a brass band will warrant different microphones than a strings quartet. At the same time, there need to be enough microphones of each type to allow multiple voices and/or instruments to be recorded at once. For the purposes of this design, two edge cases are considered: a small band of at most six instruments, and a podcast with five voices. Given the small area of the room, these two cases should reasonably encompass all possible situations. For a band with loud brass instruments, dynamic microphones are best suited for the job. For upper-range stringed instruments and human voices, a small-diaphragm condenser would work best. For lower-range strings and voices, a medium or large-diaphragm condenser is better. Therefore, a good selection of microphones would include 5 or 6 dynamic microphones and 6 condenser microphones, with an even split of large, medium, and small diaphragms. There also needs to be one additional measurement microphone for fine-tuning the room ‘s acoustic treatment.

Microphones can be expensive, so price is an important factor to consider when shopping. For dynamic microphones, the Shure SM57 and SM58 are two of the most widely recognized microphones available. Internally, the two microphones are almost identical. The key difference is that the SM58 has a built-in pop filter to reduce plosives, making it more suitable for vocals (Henshall, n.d.). Due to their affordability and popularity, all six of the dynamic microphones can be one of these two. Most bands do not have more than two vocalists, so two

SM58s and four SM57s seems reasonable.

Next are the six condenser microphones. These are divided into three groups: small, medium, and large diaphragm size. There are two of each kind, each chosen for their affordability and good user reviews. For small diaphragms, the VMS ML-2 comes with a switch that allows it to pick up louder sounds without peaking. For medium and large diaphragms, we suggest the AT2020 and AT2035, respectively. Both are popular condenser microphones, and they appear visually nice on camera. The AT2035 also comes with its own shock mount. This selection of microphones should be sufficient for most use cases.

Pop filters are optional clip-on mesh screens that protect microphones from puffs of air produced when speaking. These usually cost only around $20, regardless of vendor, so they left out of the price analysis.

Finally, there is the measurement microphone. This is a special type of microphone used to measure the frequency response of the room. The website for Room EQ Wizard (REW), a free software for measuring frequency responses, suggests using the Dayton Audio EMM-6 measurement microphone (Mulcahy, 2022). A later section will discuss how this microphone is used. The cost of the EMM-6 is $80.

On top of all of this we will need microphone stands and clips (the part that connects the microphone to the stand). Many microphones come with their own clips, and basic microphone clips tend to be quite cheap (less than $10 each), so they are excluded from the cost analysis. Shock mounts are special clips that absorb low frequency vibrations transferred up from the floor. Gator Frameworks sells cheap shock mounts for $30, so two are included for the studio. For a band of six standing players, we need six tall microphone stands. The MS7701B is one such mic stand that can extend from three to five feet tall. There may also be times when a floor-level microphone mount is necessary, such as for a cello or a bass drum. For this, the GFW-MIC-0821 extends only one to two feet. Two of these are included in the plan. For a five-person podcast, five desk-mounted stands, such as the DS7200B, would be useful. These three brands of microphone stands were chosen based on their affordable prices and positive buyer reviews. As always, other similar products could easily be substituted.

Next, there needs to be an audio interface with enough ports to support at least six microphones simultaneously (continuing with our edge-case example of six instruments). Many audio interfaces come with more than six inputs, but these are often “line” inputs, which are meant for electronic instruments and are not necessarily suitable for microphone signals (Neumann, n.d.). Specifically, an interface must have six microphone inputs in the form of “XLR” connectors, which is the type of 3-pin input connector used by most microphones. For this purpose, we recommend the Focusrite Scarlett 18i20 3rd Gen, which costs about $550. It can be mounted on a tabletop or a server rack, and it has 8 XLR inputs for microphones. This should be more than enough input. It plugs into the computer with a USB 2.0 connection, but also requires a source of external power. The reason this interface is recommended over other brands is that Focusrite is already a widely used brand of audio interfaces. Someone using the studio for the first time may already be familiar with the brand, and software support for common operating systems (namely Windows and MacOS) is unlikely to be dropped soon. The 18i20 also comes with many extra line inputs and outputs if the need for those ever arises.

Professor Bianchi suggests that there should be a computer dedicated solely to audio editing. The audio computer would combine the microphone inputs into a single stereo track, while the streaming computer would combine that stereo mix with the video from the cameras. The purpose of this would be to take some of the processing load off of the streaming computer to reduce potential stuttering problems. This comes with the added challenge of finding a way to send the stereo audio track from the audio computer to the streaming computer without sacrificing sound quality. While a few software solutions exist, they introduce additional network latency and are subject to lossy compression. The cleanest solution would be to connect a smaller secondary audio interface to the streaming computer. The output of the main 18i20 interface would be connected directly to the input of the secondary one. This comes with the added benefit of being able to connect the studio monitors to the streaming computer instead of the audio computer when desired. To keep the brands consistent, a good secondary interface would be the Focusrite Scarlett 2i2. It is essentially a tiny version of the 18i20 with only two inputs and two outputs. The 2i2 is small enough that it does not require an external power supply. It needs two inputs because a stereo track has both a left and right channel.

The control room should have at least two high-quality monitors for stereo playback. These are audio monitors, not to be confused with digital displays. Professional-grade monitors are designed to playback audio as accurately as possible. Most studio monitors have similar audio ranges and features, so choosing the right ones comes down mainly to price and what brands people trust most. Only two studio monitors are needed, as the LEDE control room design does not easily accommodate surround-sound systems. The control room would also benefit from a subwoofer for better playback at ultra-low frequencies. At Professor Bianchi’s suggestion, we chose to use a pair of JBL 305P MkII 5-inch studio monitors. These are moderately high-end speakers that cover most of the audio spectrum (43Hz to 23kHz). The tweeter on the top of the speakers has a horn-shaped inset that is advertised to widen the optimal listening zone. Switches on the back adjust the high and low frequency output to better suit the room they are used in. The monitors can be purchased alongside the LSR310S 10-inch subwoofer.

The two monitors should also have stands/mounts to keep them acoustically isolated from the floor. This has the added benefit of raising the speakers off of the table to reduce unwanted reflected sound. Gator Frameworks sells a pair of desktop monitor stands that costs $100 in total. Fortunately, a lot of these audio devices are modular. If the need arises in the future, more microphones or a larger audio interface may be incorporated without drastically altering the rest of the audio system.

Audio Cables

Finally, there are the cables required to hook everything together. Length, quality, and connector types are of key concern here. The microphones all use XLR type connectors, but certain electric instruments require quarter-inch TRS or TS connectors as well. For convenience, a “snake cable” should run between the two rooms. A snake cable is a thick cable that bundles many smaller cables together into a manageable tube. Having one or two snake cable extenders permanently installed between the rooms would allow microphones/instruments in the studio room to be plugged into the audio interface in the control room. The Hosa Little Bro’ 6x2 cable contains six XLR extenders and two TRS extenders and costs $76. This would support six microphones as well as two TRS or TS ported instruments. In the studio room, we will also need extender cables to attach the microphones and instruments to the end of the snake. There is a huge variety of these cables available depending on how long and durable they need to be. For XLR extenders, the example used for cost analysis is the Pro Co EXM-25, which comes with a lifetime replacement warranty and reaches 25 feet. For the TS extenders we have the Pro Co EG-20, which has the same lifetime warranty.

Next there are the cables for attaching the monitors and subwoofer to the interface output.

None of these cables need to be very long since the monitors and interface will be right next to each other. Based on the ports available on the JBL monitors and subwoofer, we will need two TRS to TRS cables to connect the subwoofer and two TRS to female-XLR cables to connect the monitors. The monitors are plugged into the subwoofer, which is plugged into the audio interface. For TRS to TRS we went with the Hosa CSS-105, and for TRS to XLR we went with the Pro Co BPBQXF-5.

Finally, there needs to be two more TRS to TRS cables to connect the two audio interfaces together. The total cost of all the audio cables is listed below in Table 2.3:

Cable Type	Product	Count	Unit Price	Total Price
Room-to-room Snake Cable	Hosa Little Bro' 6x2 25ft	1	$76	$76
Studio Snake-to-microphone	Pro Co EXM-25	6	$30	$180
Studio Snake-to-instrument	Pro Co EG-20	2	$21	$42
Interface to Subwoofer and Interface to Interface	Hosa CSS-105	4	$8	$32
Subwoofer to Monitor	BPBQXF-5	2	$20	$40
			Total:	$370

Table 2.3: Cost Analysis of Audio Cables

In summary, the total cost of materials for the acoustic treatment, audio equipment, and audio cables comes out to roughly $9,060.

Audio Software

The last piece of the audio puzzle is the software. Digital Audio Workstations (DAWs) are software packages that are used to edit audio tracks. There are many DAWs available depending on your needs and budget. These days there are even fully-featured DAWs that are completely free, such as Audacity and Garage band. Unfortunately for our use case, most DAWs are not designed with live-mixing in mind. This can be an issue if the audio software cannot keep up with the rest of the stream, causing noticeable lagging or stuttering. This is why we recommend Ableton Live, as it is one of the only DAWs that is specifically advertised to work in a live setting, ensuring optimal performance. A regular license of Ableton Live costs $450. For instances when live audio is not necessary, the audio computer can be loaded with a couple of other DAWs that the user can choose from based on personal preference. For this we suggest Pro Tools. In the case of two computers, these packages should be installed on the audio-specific computer.

Video, Lighting, Livestreaming Software

Considering software for other parts of the studio, the video software should be something that is capable of handling a couple of inputs very well, while also having the ability to add onto the video with effects if needed. OBS is a capable software and it's free, but it is very limited in what it can do because its only free. In this situation, vMix would be more capable and applicable to this situation. It can create overlays, has several transitions on said overlays and from video-to-video input, and can combine audio input with video input and encode it, making it ready for livestreaming without the livestreaming software needing to encode it. At $700, it is pricey, but it is a lifetime purchase with 4K streaming quality with nearly every tool in vMix's arsenal.

Moving on to lighting and livestreaming software, many different options pop up for livestreaming, as active lighting during live performances is often a necessity, and livestreams do not happen without a platform to put them on. For the livestreaming software, Vimeo is actually the preferred option, due to the ability to transmit the livestream to other platforms in addition to Vimeo, who also streams in 4K. The advanced plan, which seems pricey at $65/month, is actually decent considering it contains the ability to go to other platforms as well, meaning you are not limited to one site. As for lighting, Lightjams is a simplistic program to get active lighting up and running, and will be great for students who have never worked lighting before, while still having many functions for more experienced people to use. The most effective option for the studio at the month is the $125 Express version, which is a lifetime purchase, does everything that the lighting rig available allows Lightjams to do.

Video Cameras

The tricky part about finding the right camera for a studio of this size is finding a camera that both balances simplicity and ease of use with range and compatibility and balancing cost with quality. Adding a simple and cheap camera like the Mevo Start Live Streaming Camera may seem like a good option at the time, due to the 1080p streaming quality, remote control via Mevo app, and built-in microphone, but there are always tradeoffs. For example, there is no manual color correction, meaning that any imperfections in the camera's color streaming have to be adjusted instead with the lighting, which, as is discussed later on, will involve changing six lights. In addition, there is no physical output port, meaning that not only will the latency of the video feed be subject to the connectivity of the Mevo and streaming computer, but also that all production *must* go through the third party Mevo app, slowing down the video feed even longer. The ethernet power adapter Any latency by the video feed means that the audio and video inputs must be synced up, taking up even more time that could be used elsewhere. Though there is a USB-C port on the back that looks like it can be used for video feed, however the Mevo website strictly states that it is for audio and power only, neither of which can be used because there will already be direct audio input via the above section, and the Mevo cannot charge and stream at the same time.

Figure 2.3. Backside of the Mevo Start Live Streaming Camera. Notice the lack of physical output ports, and any sense of adjustability on the actual camera itself.

Knowing this, another problem arises: Each camera has its own tint to it, a slight shade of color it reads the world as. Knowing this, it will be difficult to use multiple different cameras on this streaming studio, as changing the lighting to correct 1 camera may make the other camera's tint worse. The answer, then, is simple: Have 3 of the same camera. This solves the issue of having to color correct each camera, but also necessitates that each camera be versatile enough to handle many different types of shots and angles.

This leads to the Canon XA11 Professional Camcorder. With full 4K live streaming video quality, the XA11 can provide full clear image quality, with a minimum distance of 2 feet for maximum resolution. Capable of both recording and streaming, it has a lens attachment clip that allows for different lenses and filters for a much wider array of shots, has a separate power source for both battery and wall plugs, and has a touchscreen for better accessibility. This covers most of the preferred qualities of a camera for the studio, but there are two aspects that significantly hurt it: cost and ease of use. The XA11 costs $1,689 per camera, which essentially puts it out of the price range, as that price tag is the camera by itself, not including necessities such as a memory card, camera case, and tripod. In addition, the camera requires at least some levels of knowledge about photography and film technology in order to use all the functions of the camera, which may make it a poor choice for students looking to start getting into a live streaming lab.

With these considerations in mind, the most efficient and likely best camera to choose would be the Blackmagic Design Pocket Cinema (4K). Full touchscreen, interchangeable lenses, HDMI, USB-C, and XLR ports, battery powered and cord powered, 4K streamed and recorded video quality, and 64GB of memory included. The price, at $1,295, may seem a bit steep at first, but considering that both spare battery, 64GB memory card, and case are all included, it comes out as significantly higher value than competitors, especially the XA11, which by itself was $400 more. Due to its versatility, ease of use, and cost, the Blackmagic is the best option for this livestreaming studio.

Figure 2.4. Blackmagic Design Pocket Cinema (4K) with Battery and 64GB Memory Card.

Video Cables & Accessories

Now that the camera is selected, the connections between the camera and the streaming computer should be considered. The Blackmagic has both an HDMI and a USB-C port, as well as an XLR port for audio if needed, but since the studio will have its own microphones, this will not be needed as often. The computer will have HDMI ports, but since USB-C ports are relatively newer, it may need a converter from USB-C to USB-A, having the HDMI be the primary mode of transmission between the camera and streaming computer may be important. For these HDMI cables, we will use Cable Matters 48Gbps 8K HDMI cable. This will also connect the monitors of each station to their respective computers. The camera also needs a stable place to stand, so we will use the CAMON 72 inch Heavy Duty Tripod for each camera, which will allow students to change the height and placement of the cameras as necessary. Having ethernet and USB switch, or nodes that combine cable inputs into one unit, will help reduce the number of wires in the studio, which will help keep track of cable management. In total, the price for the video section of the live stream studio should come out to the following:

Item	Product Name	Vendor	Count	Unit Price	Total Price
Livestream Camera	Blackmagic Design Pocket Cinema (4K)	Adorama	3	$1,295.00	$3,885.00
Wide Lens	Meike 25mm F1.8 Large aperture Wide Angle Lens	Amazon	1	$74.99	$74.99
Normal Lens	Meike 35mm F1.7 Manual Focus Prime Lens	Amazon	2	$69.99	$139.98
Tripod	COMAN heavy Duty 72" Professional Video Tripod	Amazon	3	$139.99	$419.97
HDMI Cables	Cable Matters 48Gbps 8K HDMI Cable (6.6ft)	Amazon	6	$10.49	$62.94
USB-A Switch	Ugreen USB 3.0 Sharing Switch (4 Port, 2 Computers)	Ugreen	1	$40.00	$40.00
Ethernet Switch	NETGEAR 5-Port Gigabit Ethernet Unmanages Switch (GS305)	Amazon	1	$22.99	$22.99
USB-A Cables	Mediabridge USB 3.0 (8 Feet)	Amazon	5	$14.99	$74.95
				Total:	$4,720.82

Table 2.4. Total Cost of Video Transmission.

Lighting & Other

Lighting may seem like a daunting task for this specific situation, but it is actually relatively simple. All that needs to be done is to cover the center of the room in light from multiple angles to ensure that all areas of the subject are appropriately lit. Because the room itself is rather small (10 feet x 15 feet), there does not need to be that many lights. Because of this, the Chauvet DJ 6 Spot RGBW 6x9W System would be excellent for this. At only $309, it has 6 spotlights that can change color with another input from a computer in the control room, via Lightjams. It has a simple DMX in and out port that requires XLR cables, for which we already have the snake cable. The only trouble would be mounting it to the wall or ceiling, but once it's there, it takes up very little space.

Figure 2.5. Chauvet DJ 6Spot RGBW 6x9W System.

With the lighting in place, the main component left is the uninterruptable power supply to make sure nothing happens to the power being supplied to each system during the live stream. Two will be needed: one for the studio and one for the control room. They should each be capable of handling all of the computer, audio, and video systems in the room. For this, the APC 1500VA UPS Battery Backup and Surge Protector would be best suited due to its high capacity in both Watts and Volts, at only $169.

Results & Findings

Computer Hardware Installation

When processing live footage, a powerful computer is essential. The first thing to consider is the hard drive. When editing video, you have to consider the I/O performance of the host. I/O performance is the input and output of data, that is, the data flow and data throughput per second. In particular, the data volume of 4K is more than 4 times that of HD, which brings huge pressure on computing and storage systems. The host needs to have strong I/O performance to guarantee it. The overall I/O performance of the host includes not only the hard disk speed, but also the motherboard interface speed, motherboard frequency, memory size, memory frequency, dual-channel memory, CPU L3 cache size, and the memory frequency supported by the CPU. Nowadays, the configuration performance of computers is becoming more and more powerful, but in the entire computer system architecture, compared with the CPU and memory, the speed of the hard disk is the weakest device in the PC. Computer CPU + cache + memory + hard disk + graphics card is more like a relay race combination. The speed of the whole combination is related to each component, and the baton is data. Often the baton is passed to the hard disk and it lags behind. An ordinary mechanical hard disk, the speed is generally 100MB/s, and it can only reach 30MB/s when it is lower. The transmission speed required for editing 4K material is 400M/s, so the speed of the array needs to be increased, and the speed of the array with RAID5 can reach 420MB/s. Enough to edit in 4K. The speed of solid-state drives is faster, and now the speed of solid-state drives is 500M/S.

Parameter	SSD	HDD
Abbreviation of	Solid State Drive	Hard Disk Drive
Cost (Estimate)	$80 for 1 TB	$40 for 1 TB
I/O Performance	6000 io/s	400 io/s
Weight	0.1 Pounds	0.3 Pounds
Durability	Roughly 5x Compared to HDD	1 Failure ~ 300,000 Hours
Energy Consumption	2-5 Watts	6-15 Watts
Life Span	10+ Years	3-5 Years
Noise	Low Noise	Moving Parts Produce Notable Noise
Technology	Integrated circuit using Flash Memory	Spinning Disks/ Platters
Target Devices	Modern Laptops	Desktops & PCs

Table 3.1. Comparison of SSDs and HDDs.

The second consideration is memory. Memory is a must for anyone who relies on a fast and efficient computer to edit video. Video editing software uses more RAM (random access memory) than most computers have, and without enough memory, it's almost inevitable that your computer will crash or freeze while editing video. The exact amount of memory required for video editing will depend on the software you are using, the type of movie you are editing, and the number of different applications or programs you are using at the same time. For a smooth video editing experience, you may need to add more memory. Increasing memory is critical to all aspects of the video editing process, and is recommended for any video editor looking to revitalize a slow machine. RAM (Random Access Memory) is the short-term memory of your computer that allows you to access multiple programs at the same time very quickly and efficiently. In contrast, a computer's mechanical hard drive, or solid-state drive, is long-term storage that keeps information longer. Whether editing emails, documents, or videos, these tasks require RAM. How much RAM you need depends on the type of work you're doing and how many things you're doing at the same time. For video editing, the memory capacity of your computer or laptop is critical to your workflow. Without enough memory, the computer cannot perform the required tasks, and video editing becomes unnecessarily difficult. Simply put, the more RAM a computer has, the faster it runs. You need enough free memory for your computer's operating system to load, to open the video editing software you need, to edit video easily, and to keep your computer's background tasks running. Also, you might want to take into account that any other apps that are open, such as OBS, also require a lot of your computer's RAM.

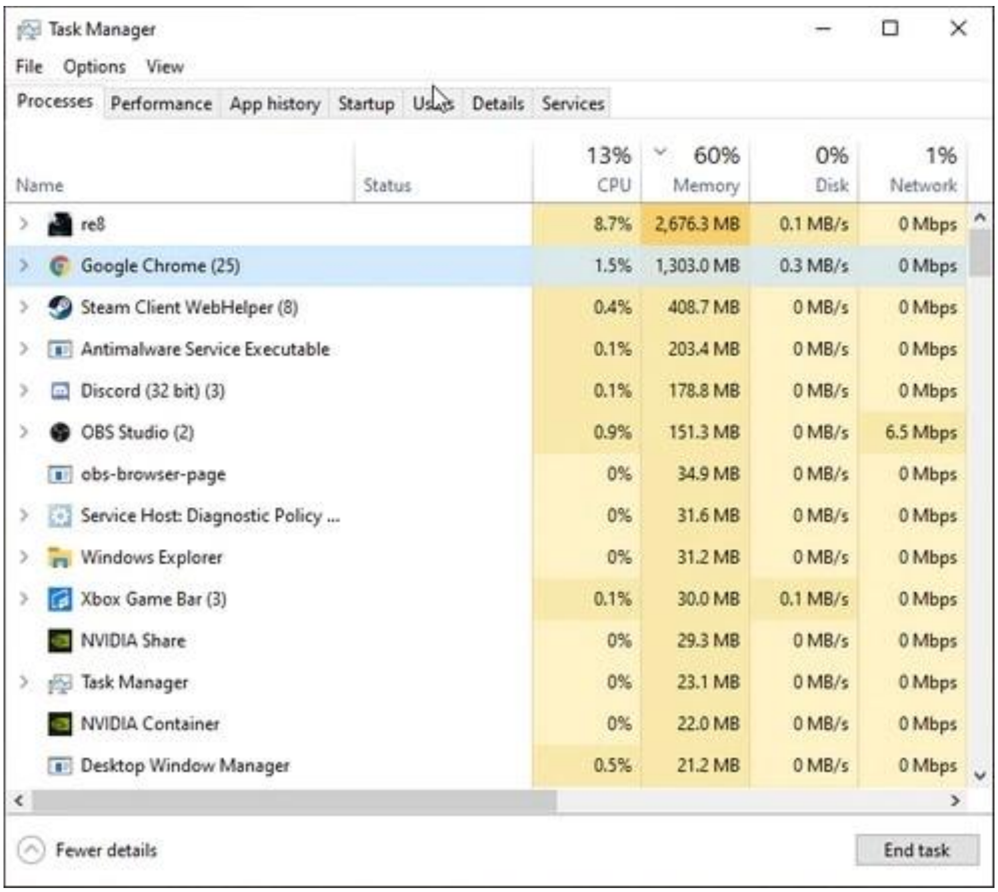

Figure 3.1. Example of Memory Usage while Streaming on OBS.

64GB is the most efficient computer RAM capacity for video editing. With 64GB of RAM, you can run multiple programs simultaneously while still being able to edit and preview videos without spending excessively on options that might otherwise never get used. 64GB lets you do everything you need for video editing without slowing down your workflow.

The third point to consider is the CPU. All video codec work requires the CPU to handle, and the CPU is the data center in the entire clip. Therefore, the CPU, like the motherboard, is also a bridge between the memory and the hard disk. The processing speed of the CPU affects the speed of data flow. At the same time, live streaming can also put a strain on the computer. This pressure is also the first thing to pay attention to is the push flow. In the case of OBS, the mainstream encoder is X264. Using X264 for the encoder can achieve significantly better results than other encoders. Specifically, when using the CPU to push the stream and the graphics card to push the stream, the picture of the CPU push is more refined than that of the graphics card. So what are the substantive requirements for the CPU? For the CPU, the higher its main frequency, the more operations per second, and the faster the calculation speed. The greater the number of cores and threads, the stronger the parallel computing capability and the higher the overall data processing efficiency. Like when editing video, a multi-core/multi-threaded CPU makes preview generation much faster.

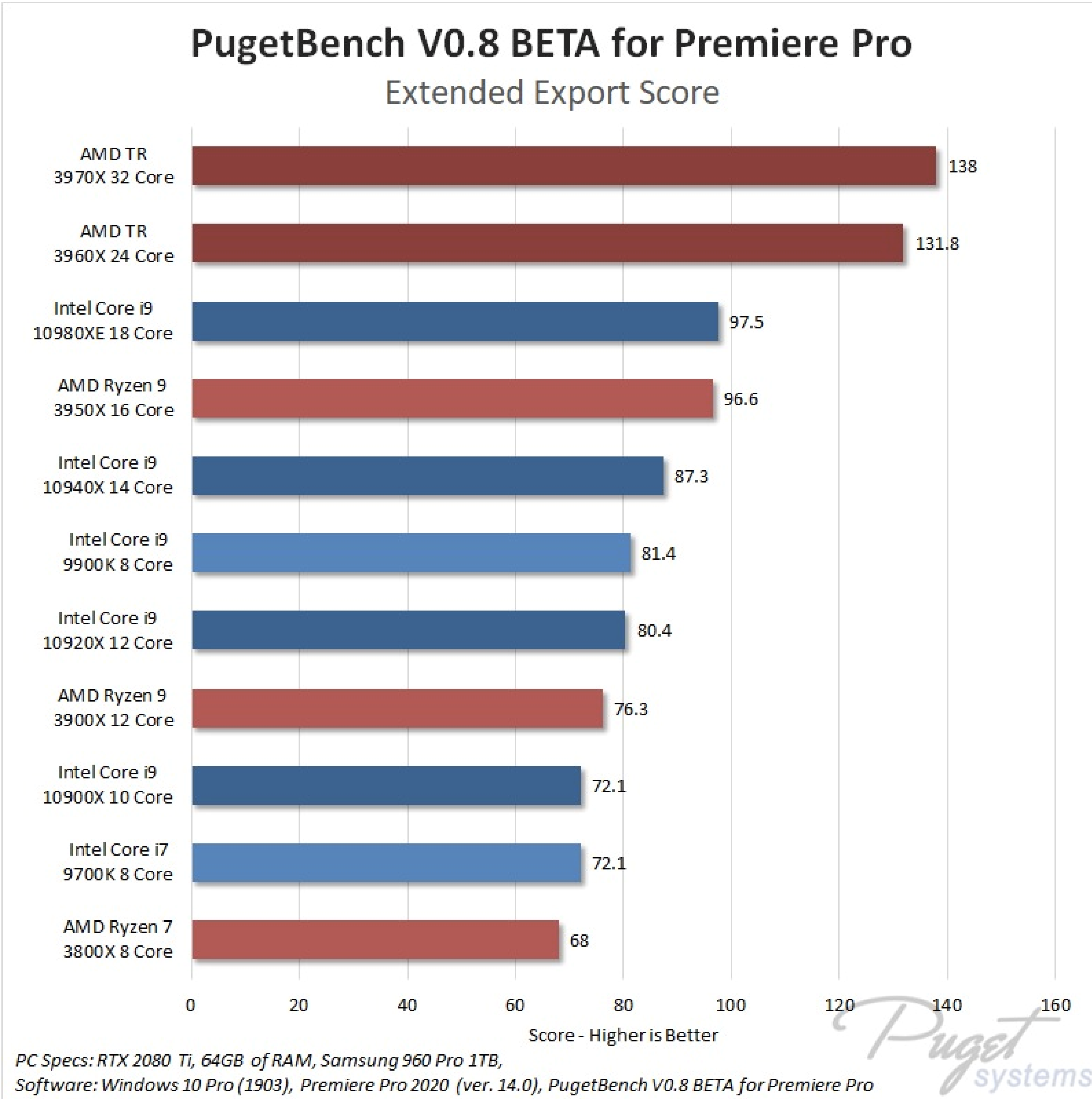

Figure 3.2. Scores for CPUs, Courtesy of Puget Systems.

As can be seen from the figure, when the CPU has more core counts, its comprehensive ability in processing video will be stronger. There will be no stuttering and so on. The following is the resulting cost of the streaming computer now that every part has been decided:

Item	Product Name	Vendor	Count	Unit Price	Total Price
CPU	Intel Core i9-9900X, 10 Core	Intel	1	$650.00	$650.00

Motherboard	EVGA X299 Micro	Amazon	1	$287.99	$287.99
CPU Cooler	Hyper H412R CPU Air Cooler ‘4 Heat Pipes	Cooler Master	1	$32.99	$32.99
Case	Fractal Design Focus G – Mid Tower Case -ATX	Newegg	1	$62.00	$62.00
Graphics Card	Asus Radeon ROG-STRIX-RX560-O4G-GA	Asus	1	$250.00	$250.00
RAM	Crucial 32GB Kit (16GBx2) DDR4-2133 MT/S(PC4-2133) CL15 Dual Ranked X4Based ECC Registered Server Memory	Amazon	2	$105.27	$210.54
Storage	Samsung EVO 970 Plus 1 TB Pcle Gen3 x4 NVMe M.2-2280 Internal Solid State Drive (1024MB Cache Memory)	Samsung	1	$96.00	$96.00
Power Supply	EVGA SuperNOVA 1000 G5 Power Supply	Amazon	1	$179.99	$179.99
Monitor	Sceptre E248W-19203R 24” Ultra Thin 75Hz 1080p LED Monitor	Sceptre	2	$95.98	$191.96
Thermal Paste	Arctic MX-4 (8 Grams) Thermal Compound Paste	Amazon	1	$6.65	$6.65

Keyboard	Logitech MK270 Wireless Keyboard	Logitech	1	$29.00	$29.00
Mouse	Logitech M510 Wireless Computer Mouse	Logitech	1	$17.50	$17.50
				Total:	$2014.62

Table 3.2. Total Cost of Streaming Computer.

Camera Installation

In order to test the hypothetical solution stated under the video camera section in methodology, an initial livestreaming test using a standard Nikon D5300, and using the livestreaming software vMix. The first step is to see the available ports and determine the best connection port to live stream the video from the D5300. Below is the available ports on the D5300.

Figure 3.3. Available ports on the D5300, which include Mic Out, A/V Port, and HDMI.

In the absence of a BNC port, the mini-HDMI connector was used to take out the HD video from the D5300 to the laptop with the livestreaming software vMix. However, the intial connection failed because the mini-HDMI to HDMI cable used did not use a converter to switch the HDMI signal to USB-C, one of two input ports on the laptop. An additional HDMI to USB-C converter and USB-C cables were added to the connection between the D5300 and the laptop. Using this, the laptop successfully read the camera as a visual input. A Blue Snowball microphone was also plugged into the laptop in the USB-A slot, with the laptop reading the microphone as an audio input faster than the camera.

After this, vMix was downloaded and booted up. Two new inputs were created via the "Add Input" tab in the bottom left. One for the D5300 and one for the Snowball, both of which took very little time. After that, it was discovered that the visual input for the D5300 would shut off every 30 min, requiring a manual restart. Several hypotheses were made, but the ultimate reason came down to international tax law. According to the Explanatory Notes of the Combined Nomenclature of the EU, On the 23rd of October, 2007, Official Journal C248, Section 5, Pages 5-6,

"In general, the digital video camera recorders of these subheadings have the design which differs from digital cameras of subheading 8525 80 30. They often have a foldable viewfinder and are frequently presented together with a remote control. They always offer an optical zoom function during video recording.

These digital video camera recorders may also have still image recording capability.

Digital cameras are excluded from these subheadings if they are not capable, using the maximum storage capacity, of recording, in a quality of 800 × 600 pixels (or higher) at 23 frames per second (or higher) at least 30 minutes in a single sequence of video." (European Commission, 2007)

Now, because of this “digital video camera” manufacturers needed to trim the maximum recording time of most video cameras down to below 30 minutes, so as not to increase the tariff on their products from 4.9% to 14%, thus driving down demand for their product. As a result, the Nikon D5300 cannot record or stream for longer than 29 minutes and 59 seconds at a time. This issue will be resolved once the Blackmagic is purchased for the studio, but for now, the proof of concept receives all inputs and is ready to stream.

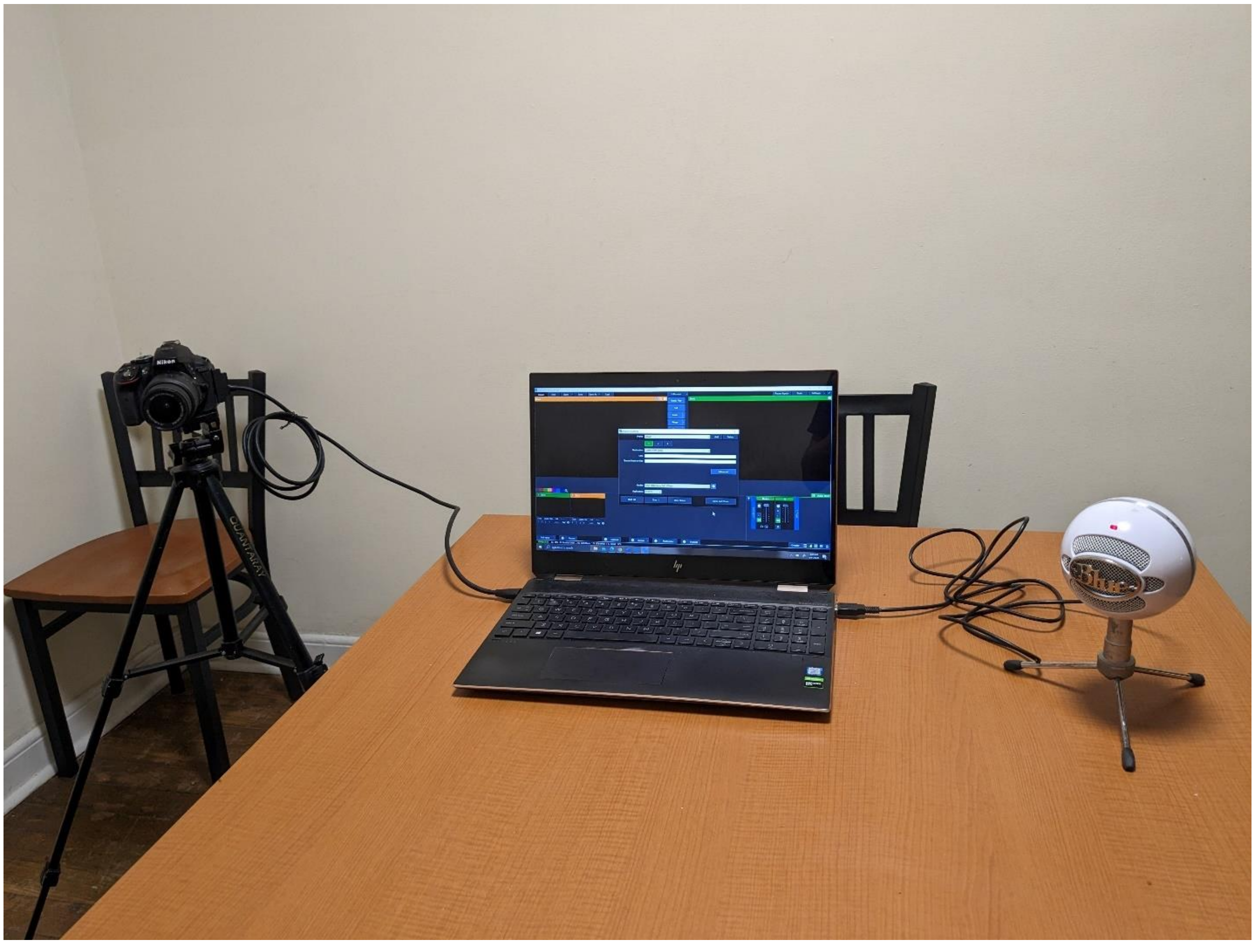

Figure 3.4. Full Proof of Concept for the Livestreaming Studio.

Wiring

The wiring for the audio equipment is fairly simple, and all the necessary wire types are detailed in the audio cables. Figure 3.5 is provided as a visual aid for hooking everything together. The cable connection types are indicated in small letters. To pass the snake cable between the studio and control rooms, a hole must be drilled through the wall. After all the wiring is complete, the edges of the hole should be sealed with caulk to create a soundproof barrier. Figure 3.5 does not include external power connections. Some electronic instruments in the studio room may also require external power.

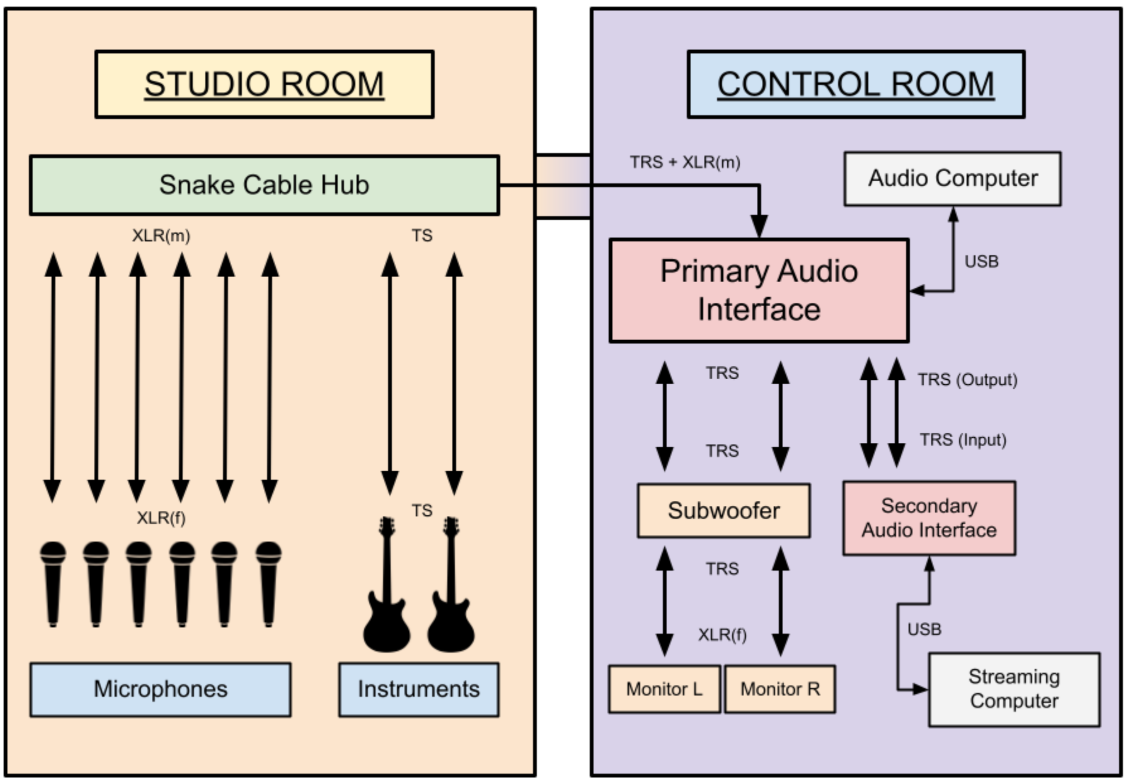

Figure 3.5: Audio Equipment Wiring Guide.

Camera wiring is not as challenging either, as the video input cables can be plugged directly into the streaming computer using an extension cord between the rooms, as the streaming computer will have enough ports without the need for an additional accessory to manage the video inputs. As for power, primary power strips should be laid in each room, Because every device listed, with the exception of microphones, instruments, and the snake cable hub needs to be connected to a wall outlet.

Acoustics Calibration Using Room EQ Wizard

Once all the hardware is in place, you can begin adjusting the acoustics of the room using a free software called Room EQ Wizard (abbreviated as REW). The EMM-6 calibration microphone should come with a downloadable calibration file used by REW to remove bias from the input signal. REW will also need to generate a calibration file for the audio interface. To do this, the output of the interface must be plugged directly back into its input. Then run the calibration program built into REW, which will generate the file. After the hardware calibration is finished, the software is now ready to take measurements of the room's frequency response. These measurements are used to find the optimal listening position, speaker placement, and amount of absorptive paneling. They can also reveal unexpected acoustic defects in the room that may require additional treatment. The specifics of using REW are outside the scope of this paper. More in-depth tutorials are available on the internet and on the REW website.

Manuals on How to Operate the Studio

How to Power on the Studio:

NOTE: Do not unplug the UPS when you are powering on and off the studio! This will damage the UPS and may decrease its lifespan.

1. After turning on the light switch, turn on the power strip for the audio interface, mixer, and main streaming desktop, which should all be connected to the same power strip.
2. Once the power for the desktop is on, load on the lighting program Lightjams.
3. After Lightjams is on, press the power switch for the power strip for the Chauvet lighting fixture.

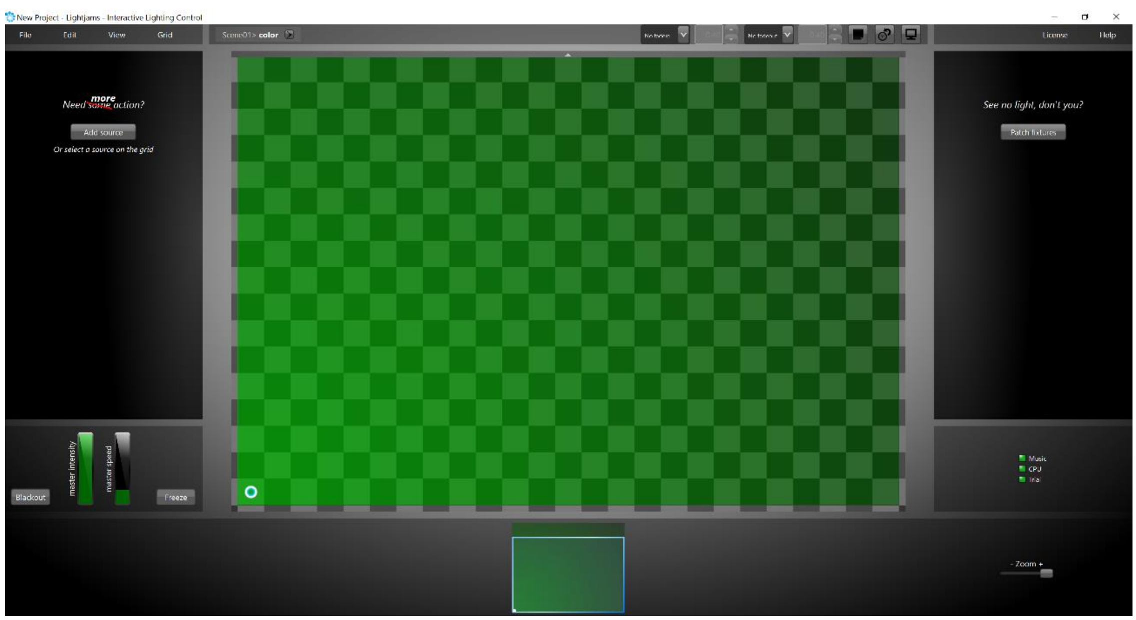

Figure 4.1. Blank Lightjam Project; Opens when the Lightjam Application is Loaded.

4. After the lighting fixture is turned on and you can see that all lights have power, load the lighting preset “Baseline” in Lightjams.

   - Go to “File” > “Open” > “Baseline.ljp”. All openable files in Lightjam are .ljp files.

   This will bring up the lights to a normal, white light that can be adjusted if needed, but will be good for most use cases.

How to Add a Camera in vMix:

1. Select the camera that you want, and check the ports on the side to see what type of cable it needs.
   - If it has a small circular port, it requires a BNC connector.
   - If it says “HDMI” next to a trapezoidal pin, it requires a HDMI cable.
   - If it has a little square of clear plastic, it requires an ethernet cable.
2. Connect the camera to a power outlet, or insert a battery, and power the camera on and activate the “Live Capture” function, usually a lever on the side of the camera.

Figure 4.2. Live Capture Lever (LV) on a Nikon D5300 Camera.

3. Attach necessary video cables from auxiliary ports to the inputs on the desktop.
4. Open vMix on the desktop. An empty project should appear on the screen.

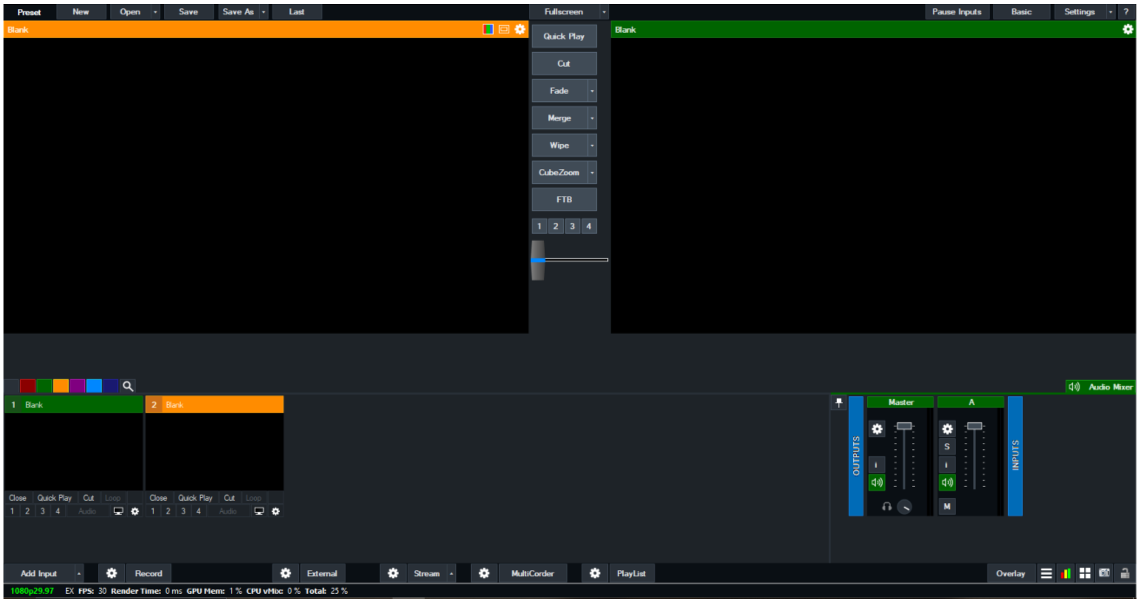

Figure 4.3. Blank vMix Project

5. Go to “Add Input” > “Camera” and look for the name of the camera you just turned on.

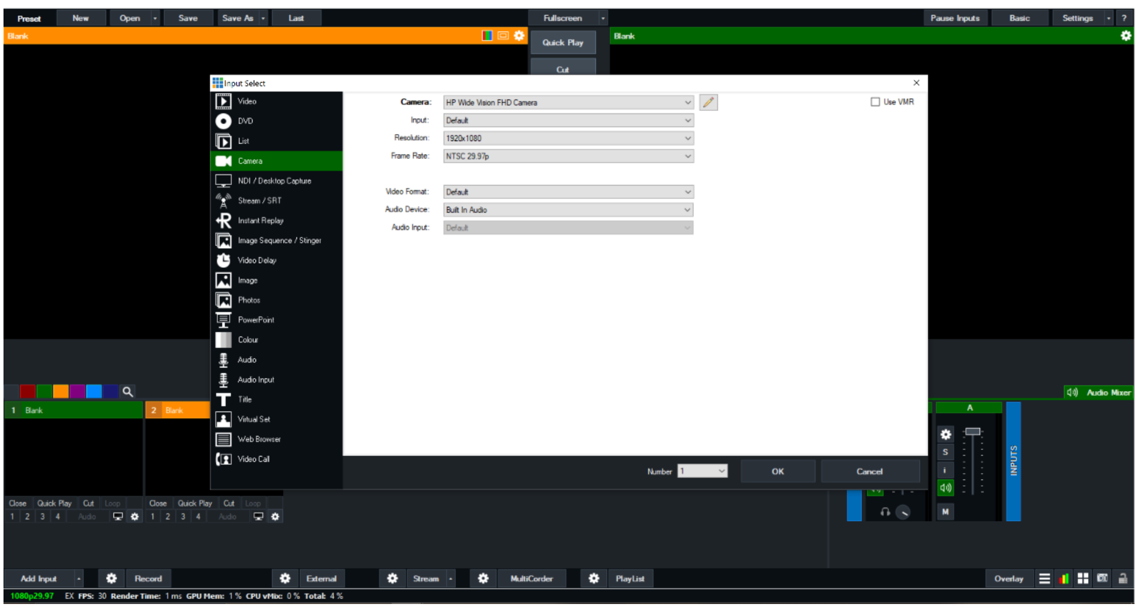

Figure 4.4. Adding a Camera to vMix.

How to Add an Audio Input in Ableton Live:

1. Decide whether the audio input is a microphone or an instrument and choose the appropriate output cable.
   - For microphones, an XLR cable is needed.

- For instruments, a TS cable is needed.

2. Connect the output cable to the snake cable hub. This will allow the primary audio interface to pick up the audio input.
3. After everything is connected, open Ableton Live, select a track, and go to "Live" > "Preferences" > "Input Config" and choose the audio input.

How to Set up a Livestream:

1. Assuming everything is powered on and connected, go to the streaming computer with vMix on it and confirm that Ableton Live's output audio is connected to vMix's input audio.
   - If Ableton Live does not output audio, go to "Live" > "Preferences" > "Audio Device" and choose the streaming laptop as the output. Additionally, in the "Preferences menu go to > "Output Config" and confirm that Ableton Live is sending audio outputs 1&2. This should output the audio from the audio computer to the streaming computer.
   - If vMix does not recognize any new audio input, go to "Add Input" > "Audio Input" > Select the USB port connected to the audio computer.
2. On vMix, the green is the video that is the current output, with the yellow window being the video input on standby. Load the input video that you want into the green window by clicking on it.
3. Test the audio outputs using the headphones to check that everyone's audio levels are appropriate.

Sending a Livestream to Vimeo:

1. Once you have everything ready to go, go to "Stream Settings" > "Destination" and

select Vimeo.

- Check to make sure that the quality is set to H264 1080p.

2. Click “Start 1”.
3. Go to Vimeo and select “Library” > “New Video” > “Create Event” > “Choose Event Type” > “Next”
4. Input the information about the event you are livestreaming, and click “Next”.
5. Select “Stream with Vimeo” under “Manage Production”, and click “Start Event.”

Conclusion

Every technical part of the proposed live streaming studio has been thoroughly analyzed, considered, and built upon by the next component. The proof of concept for the video camera and livestreaming software is functional, and can be built upon for the final product. Each part has been properly planned. The total cost for all technical aspects of the livestreaming studio is:

Section	Name	Price
Acoustics	Acoustic Treatment	$5,320.00
Audio	Audio Equipment	$3,370.00
Audio	Audio Cables	$370.00
Software	Ableton Live	$450.00
Software	Lightjams	$125.00
Software	vMix 4K	$700.00
Software	Vimeo Advanced+	$780.00
Video	Video Transmission	$4,720.82
Lighting & Other	Light Rack and UPS	$647.00
Encoding	Streaming Computer	$2,014.62
	Total:	$18,497.44

Table A: Total Technical Cost of Proposed Live Streaming Studio.

All this, however, is simply a proposal for the technical side of the lab. Labor costs, tax, furniture, and any unexpected maintenance costs beyond the first year are not accounted for. And all of this is just hypothetical. The only way to know for certain that all this is correct is to actually build and test it. After all, it's okay to aim higher than previously thought.

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Appendix A

The Python code used to generate the mode frequency graph seen in Figure ## is included below.

```
import matplotlib.pyplot as plt
import numpy as np
from collections import Counter
import math

#=======================CONSTANTS=======================#
C = 1130            #Speed of sound in feet per second
L,W,H = 10,15,10    #Room dimensions in feet

#Graphing and calculation parameters
X_MIN = 10          #Min frequency in Hz
X_MAX = 400         #Max frequency in Hz
MAX_MODE = 30       #The maximum number of loops when calculating modes. You probably
don't need to change this.
ROUNDING = 1        #The number of decimal places to round the frequencies to

#=======================CALCULATE MODES=======================#
a_freqs = []    #Axial mode frequencies
t_freqs = []    #Tangential mode frequencies
o_freqs = []    #Oblique mode frequencies

def get_frequency(p,q,r): #Gets frequency given mode numbers
   return C/2 * math.sqrt((p/L)**2 + (q/W)**2 + (r/H)**2)

for p in range(0,MAX_MODE):
   for q in range(0,MAX_MODE):
       for r in range(0,MAX_MODE):

           freq = round(get_frequency(p,q,r),ROUNDING) #Calculate frequency

           if freq<X_MIN:
               continue    #Ignore out-of-bounds frequencies
           elif freq>X_MAX:
               break       #Don't need to calculate any higher modes

           #Add mode to appropriate List
           if (p+q==0 or p+r==0 or q+r==0):#Mode is Axial
               a_freqs.append(freq)
           elif (p==0 or q==0 or r==0):    #Mode is Tangential
               t_freqs.append(freq)
           else:                           #Mode is Oblique
               o_freqs.append(freq)

#Counters keep track of how many times a particular frequency appears in the List
a_counter = Counter(a_freqs)
t_counter = Counter(t_freqs)
o_counter = Counter(o_freqs)

#=========================PLOTTING=========================#
fig,(ax1,ax2,ax3) = plt.subplots(3)

#Axial Mode Plot
x_vals = list(a_counter.keys())
y_vals = list(a_counter.values())
ax1.bar(x_vals,y_vals,color=(250/255, 142/255, 10/255))
ax1.set_xlim([X_MIN,X_MAX])
ax1.yaxis.set_ticks(np.arange(0, max(y_vals)+1, 1 if max(y_vals)<4 else 2))
ax1.set_title("Axial Modes")
```

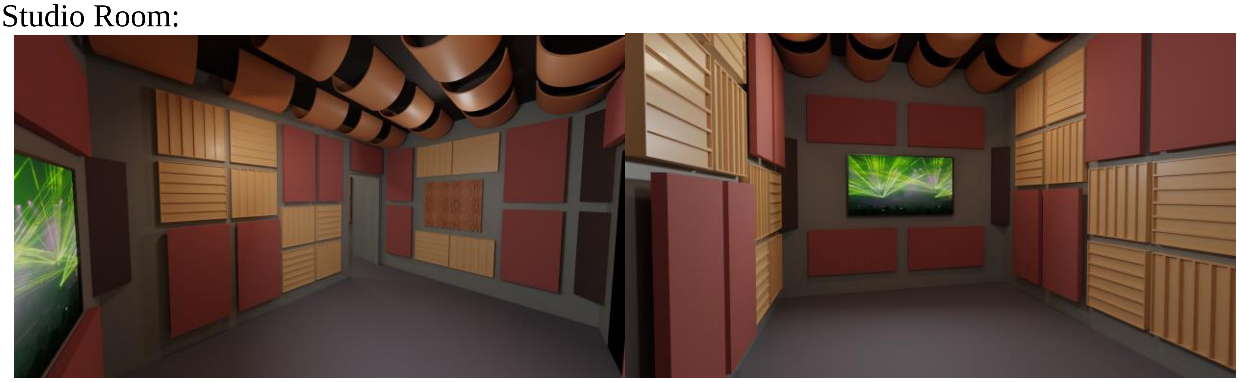
```
ax1.set(ylabel="Mode Count")

#Tangential Mode Plot
x_vals = list(t_counter.keys())
y_vals = list(t_counter.values())
ax2.bar(x_vals,y_vals,color=(7/255, 237/255, 34/255))
ax2.set_xlim([X_MIN,X_MAX])
ax2.yaxis.set_ticks(np.arange(0, max(y_vals)+1, 1 if max(y_vals)<4 else 2))
ax2.set_title("Tangential Modes (-3dB)")
ax2.set(ylabel="Mode Count")

#Oblique Mode Plot
x_vals = list(o_counter.keys())
y_vals = list(o_counter.values())
ax3.bar(x_vals,y_vals,color=(26/255, 69/255, 240/255))
ax3.set_xlim([X_MIN,X_MAX])
ax3.yaxis.set_ticks(np.arange(0, max(y_vals)+1, 1 if max(y_vals)<4 else 2))
ax3.set_title("Oblique Modes (-6dB)")
ax3.set(xlabel="Frequency (Hz)", ylabel="Mode Count")

#Display Plots
fig.suptitle("Room Modes at Low Frequencies")
plt.tight_layout() #Formatting fix
plt.show()
```

Appendix B

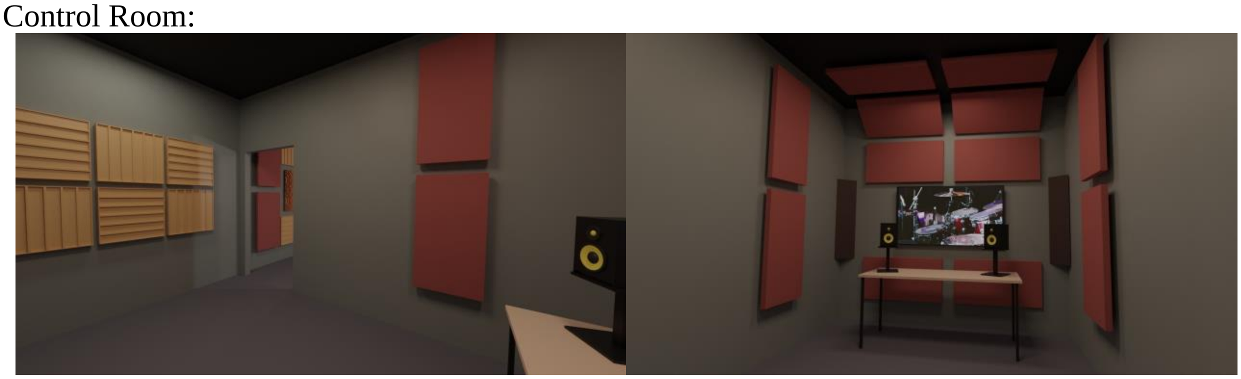
3D renders of the example room design shown in Figure 2.2. Room dimensions and wall-mounted panels are all to scale. The size of the doors, television screens, table, and monitors are all approximate. Resonating bass traps are not shown. Colors are chosen to distinguish between materials and are not representative of the final aesthetic design. Modeled in Blender and rendered with Cycles. All textures are attribution-free.

Top-Down View:

Studio Room:



Control Room:



<u>Appendix C</u>

Flow chart of the proof of concept for the camera and central streaming computer.