Buildings that Sing:
Architectural Design for Choral Performance

by

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Dalhousie University is located in Mi'kmaq'i,
the ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

I dedicate my thesis to my grandfather, Dr. Julian Brown (1936-2022), who helped nurture my love of music, art, and architecture. I wish he could have seen this thesis completed.

Contents

Abstract

Architecture filters sound, and therefore music. The design of concert halls favours a specific quality and experience of musical sound. Choral church music, which adapted to profit musically from the acoustics and spaces of a variety of church typologies, provides a counterpoint to normative concert hall design. As the number of decommissioned churches increases in Canada, these structures are ideal to be retrofitted into concert halls that draw on the historic connections between architecture, choral music, and acoustics. Working in an interdisciplinary fashion between architecture, musicology, and acoustics, I will retrofit a decommissioned church in Halifax, Canada, into a concert hall that uses music as an instrument to foster gathering while incorporating variable acoustics and performance layouts. I will build the acoustic setting of the concert hall by manipulating the triad of form, sound source location, and surface materials.

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Photograph of Notre-Dame de Paris (Lascar 2014)

Chapter 1: Introduction

> In the silence of the Gothic Cathedral we are reminded of the last dying note of a Gregorian Chant. (Pallasmaa 2005, 51)

In the restoration of Notre-Dame de Paris's ceiling and roof following the fire of 2019, will the replacement stone for the ceiling vaults be chosen to visually match the remaining stone, or to match acoustically? Notre-Dame's acoustics encouraged the evolution of choral music from single part to multi-part music in the twelfth and thirteenth centuries; its acoustics are of indubitable historic significance to the development of Western music. Yet replacement stones will most likely be chosen for their visual qualities, without much thought to acoustic properties.

Long before computer software was used to warp and modify music to the musician's preference, architecture did just that. Architecture has an enormous impact on how music is heard and performed. It dictates how performers hear themselves, how they hear others, how they hear the overall sound, and how the audience perceives and engages with the sound that is made. As such, music has had to adapt to the acoustic spaces in which it has been housed. For the past 1500 years, churches have housed choral music. Church architecture has produced a great variety of acoustic conditions, many of them quite reverberant. As choral music adapted to being heard in reverberant conditions and churches developed architecturally to house choirs, their developments became intrinsically interwoven.

The decommissioning of churches is a growing issue in Canada. Over a five month period in 2022, CBC News alone posted twenty-six articles concerning the closure of

Thomas Hooper, Victoria Conservatory of Music, Victoria, Canada, 1890 (sudoneighm 2006)

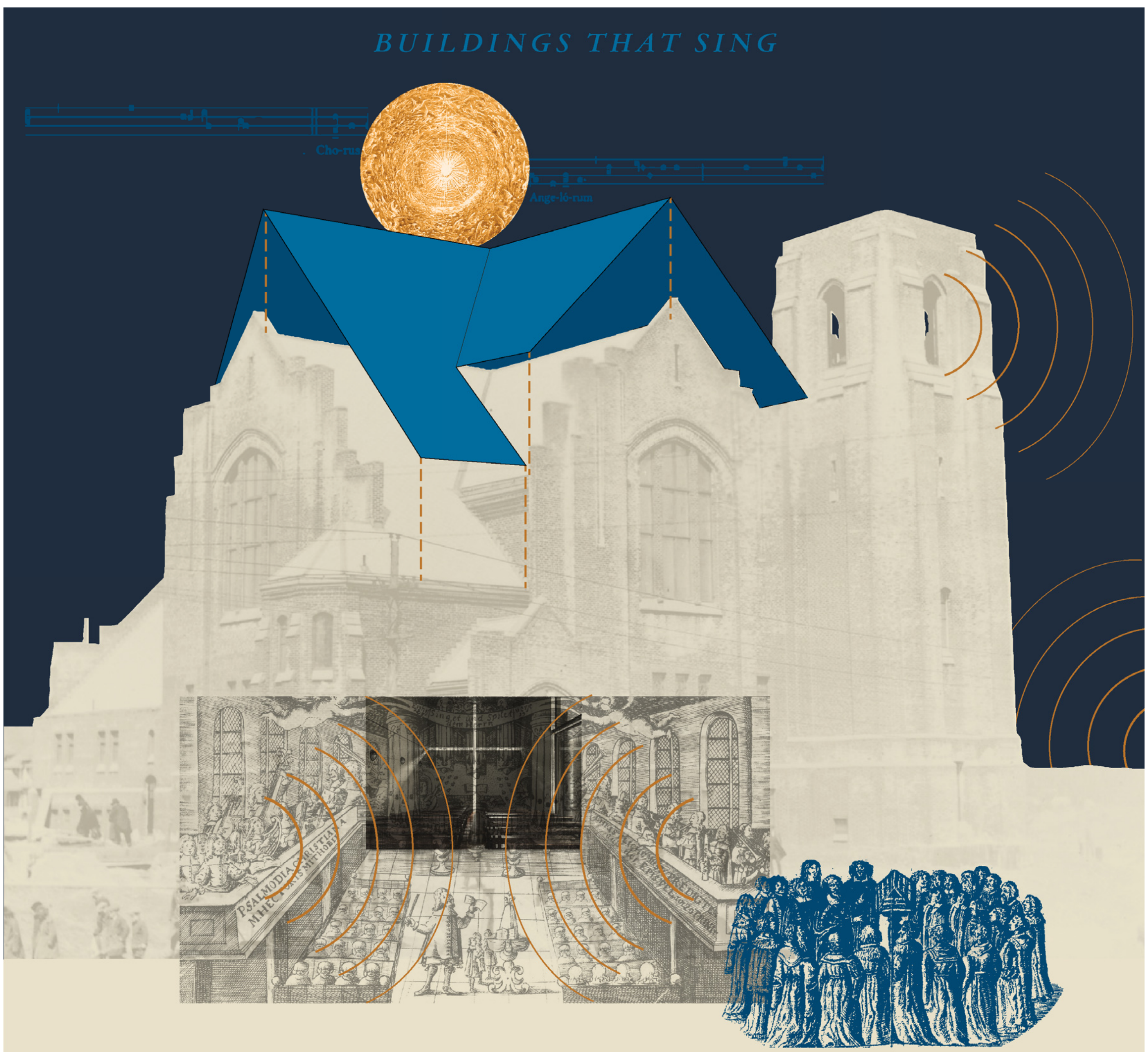
churches, potential or completed. Churches are incredibly valuable buildings in terms of numerous criteria; they contribute to architectural and cultural heritage, place making, and tourism, while housing community space and storing considerable embodied carbon. Nonetheless, the increasing secularisation of Canadian society, rising building maintenance costs, and ageing congregations are all factors contributing to congregations having to decommission and sell their churches. This has resulted in a loss of community space and historic structures. However, many churches are saved through retrofitting them for new uses. A common use for decommissioned churches that aren't demolished is to retrofit them into concert halls, which maintains these churches' positions as sites of gathering, while drawing on their existing musical foundations. This has been the case for the Victoria Conservatory of Music, housed in a former United Church in Victoria, BC.

Typically, high quality performances of classical choral music in Canada occur in concert halls. However, concert halls as a building type are quite young, the earliest of them having been designed in the 1820s (Beranek 1992, 25). Designed for symphonic or consort music, they have low reverberation times, emphasize a clear sound, are considered successful when the sound is intimate, and are designed to have sound moving in one direction from the stage to the audience. A successful concert hall therefore favours a very specific quality of sound, at the exclusion of others.

Choral music has been performed in churches long before concert halls established a certain quality of sound as the ideal. Many of the masterpieces of choral music were indeed written for performance in churches, such as J. S. Bach's famous Passion settings. Performances in churches are very different from those in concert halls; sound can come from the front, sides, back, and from above, and any combination of these placements. Additionally, the reverberation times of churches are typically much longer than those of concert halls. As such, choral church music is one such music type which is excluded by concert halls, as it has adapted to use church architecture for musical effect so uniquely. In this thesis, I will argue that concert halls do not allow these dynamic spatial relationships to continue in contemporary performance, which is an unacknowledged loss to audiences and performers, as the acoustic and architectural context that choral music was written for contributes to the character of that music.

To prove this thesis, I will draw on my experience as a choral singer to study the historic relationship between choral music, church architecture, and acoustics, a seldom researched relationship. I will use choral music as a foil to challenge the normative design of concert halls by incorporating greater flexibility of performance layouts and acoustics suited to the performance of choral music. This knowledge will be applied in a concept design for the adaptive reuse of a decommissioned church in Halifax, the United Memorial Church, into a concert hall and arts hub. To build the acoustic setting of the concert hall, I will manipulate the triad of form, sound source location, and surface materials.

This thesis will begin with an analysis of the adaptive reuse of decommissioned churches into concert halls in Chapter 2. Following this, Chapter 3 will delve into the historical relationship between church architecture, choral music, and acoustics, and will compare the performance opportunities that churches and concert halls afford choral music. I will present my design methodology for acoustically designing concert halls to suit choral music in Chapter 4. In Chapter 5, I will move to Halifax with an analysis of the site and history of the United Memorial Church. Finally, the completed concept design for the retrofit of the United Memorial Church will be detailed in Chapter 6.



Wish image

Glossary

As this is an interdisciplinary thesis straddling the subjects of architecture, musicology, and acoustics, it is important to supply to provide a glossary of terms, so that readers of diverse academic backgrounds may all equally understand the terminology used in this thesis. With this is mind, the Glossary in Appendix A is divided by subject, so that readers need only review the terms with which they are unfamiliar.

For the benefit of all readers, I will however provide clarity on two subjects: that of the multiple meanings on the word “choir,” and that of directions.

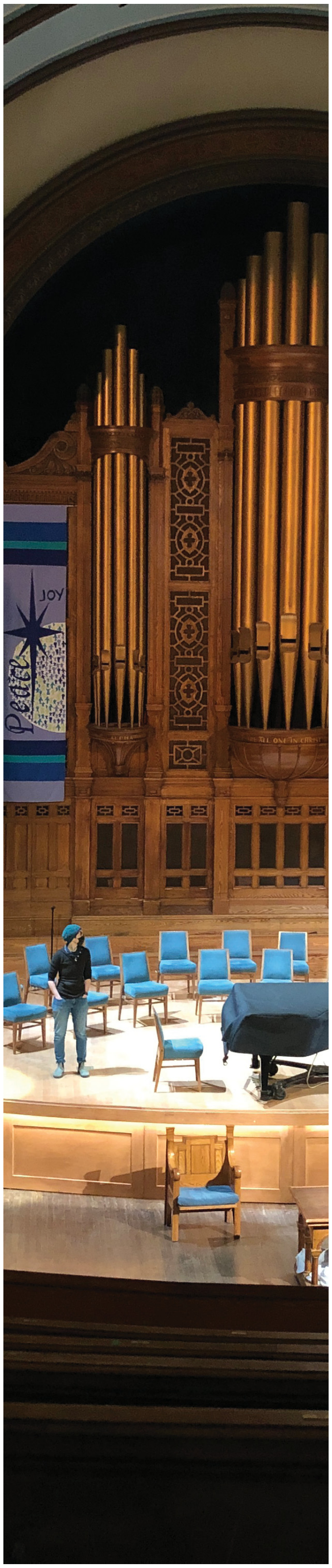
Choir vs. Quire

Unhelpfully to this thesis, the word “choir” designates both a group of singers and the part of a church from which a group of singers sing. For the sake of clarity in this thesis, I will use the words choir and quire in the following fashion:

Choir	A group of singers. In polychoral music, also refers to a sub-group of singers within the choir.
Quire	Architectural; the part of the chancel from which a choir typically sings.

Directions

In reference to church architecture, “left” and “right” will refer to what is to the left or right when looking at the high altar of a church. Similarly, in reference to concert halls, “left” and “right” will be used from the audience’s perspective, not the stage’s.



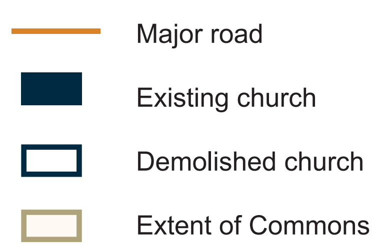
Trinity-St. Paul's Church, Toronto

Chapter 2: Adaptive Reuse

Church buildings are extremely valuable in terms of a plethora of criteria. They contribute to architectural and cultural heritage, place making, and tourism, house community space, and store considerable embodied carbon. As crucial points of community gathering for the majority of the history of churches, they are typically located at the heart of communities, thereby also occupying culturally and monetarily valuable land. Within Halifax many churches are located at major intersections, such as St. Mary's Basilica, located at Barrington Street and Spring Garden Road, and St. Andrew's United Church, located at the intersection of Spring Garden, Robie Street, and Coburg Road. All Saints Cathedral, the head Anglican church for all of Nova Scotia and the de facto church of state, is located within the Halifax Commons. And more than being landmarks within communities, "these buildings carry family memories and meaning" (Bull 2016), with many important events within individuals' lives being associated with churches, such as weddings, baptisms, and funerals.

While some people argue that "the church is really its people, not the building" (Bull 2016) and that hence conserving church buildings is unimportant, this stance overlooks the significant contribution of church buildings to tourism, place-making, and embodied carbon. It is commonly said by architects specializing in conservation and in sustainable design that "the most sustainable building is the one already built". As large buildings, churches contain enormous amounts embodied carbon. It is far more sustainable to reuse these structures than to demolish them, as is happening increasingly often as church attendance wanes

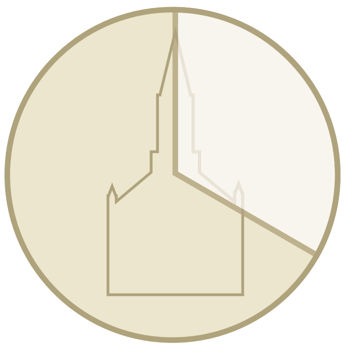
Map showing location of churches, demolished and existing, in downtown Halifax, relative to major roads (basemap from ArcGIS, 2021)



in Canada. Adaptive reuse of churches to make them into performance spaces can keep these structures alive and in business, thereby strengthening the building and its adjoining community.

Falling Use of Churches in Canada

Churches are falling out of use in Canada due to a number of factors, most important among which are decreasing congregation sizes caused by an aging congregations and rising secularization of society, and rising building maintenance costs. Often, the result of these financial burdens is congregations being forced to sell their churches to secular organizations. Given the valuable land that many churches inhabit, developers are eager to buy up churches, demolish them, and build more profitable properties. In 2016, faith groups were the second largest real-estate holders in Canada, and 30% of more than 27 000 religious buildings in Canada were likely "to be on the chopping block" in the years following (Bull 2016). With additional strain of lawsuits over sexual abuse scandals adding to the numbers of churches being sold, the loss of churches has become an important issue within Canadian communities. Between July 1, 2022, and November 30, 2022, CBC News alone posted 26 articles concerning the closure of churches, potential or completed.



30% of all religious buildings in Canada were likely to be decommissioned in 2016

Causes of Financial Burdens on Churches

The reasons for churches being closed and sold are primarily economic in nature. Increasing secularization, growing disenfranchisement with the institutions of churches, and aging congregation populations have led to churches earning less income from their congregations. As the building stock of churches ages, building maintenance fees for churches are increasing, requiring congregations with less money than usual to have greater expenses. For example, St. Bernard's Church in Digby, Nova Scotia, is set to be deconsecrated because "the small congregation simply could not afford the heating and repairs needed to keep the church going" (Ramesar 2022).

In addition to these financial burdens, Catholic churches especially have had to resort to selling their churches and other properties in order to recompense victims of physical, psychological, and sexual abuse on the part of clergy members. Thirteen Catholic churches are being sold in eastern Newfoundland (Gillis 2022) to settle claims with victims of abuse from the Mount Cashel orphanage, including the second largest Catholic church in the country, the Basilica of St. John the Baptist in the city of St. John's (Butler 2022). These abuse scandals have also caused church attendance to decrease. Patrick Butler, a journalist with CBC News, notes how some Catholics in Newfoundland stopped attending church in response to the Mount Cashel story (Butler 2022). So far, however, no churches have been sold to recompense indigenous survivors of residential schools. Given that the Catholic Church claimed to have only been able to raise $3.9 million out of $25 million to recompense survivors of residential schools (yet simultaneously spent $300 million on church construction and renovations) (Warick 2021), the number of churches sold to pay lawsuits may increase in coming years.

Easing Financial Burdens on Churches

Some congregations find ways to economically support their churches and avoid selling them. Inner city churches have been able lease spare land to developers, such as St.

St. David's, Halifax, with new apartment building located immediately behind

David's Presbyterian Church in Halifax. Situated in the heart of downtown Halifax, St. David's land is so economically valuable that they were able to lease part of their land to a developer, who will pay St. David's yearly for a century to have built a condominium on their land. However, not all churches possess such valuable or excess land. Other churches have formed partnerships with community organizations such as orchestras to economically sustain themselves. In the case of Trinity-St. Paul's United Church (TSP) in Toronto, a partnership with the acclaimed Baroque orchestra Tafelmusik was so economically advantageous that TSP agreed to collaborate with Tafelmusik in retrofitting their sanctuary to function better as a concert hall. Leasing space to such organizations, as well as to smaller organizations and non-profits, also brings churches more capital. Generally, the more people visit a church, either for church services or for secular events such as musical performances, the more economically stable a church is.

Closing Churches

Closed churches are typically sold to developers, who either retrofit them for new uses or demolish them. Examples of churches demolished to build condominiums include Willoughby Baptist and St. Jude's Anglican in Toronto, and St. John's United Church in Halifax. In city centers, small congregations with large properties are especially tempted by development potential (Bull 2016).

However, the loss of these structures can have negative impacts on communities who lose their built heritage. A congregant of St. Anselm's Catholic Church in Chezzetcook, Shirley Lowe, said that "the closure scattered the congregation … It's almost like losing a house and all the family that was in it." (CBC 2022).

Under these circumstances, retrofitting churches to house new uses can be an important way of repurposing heritage structures without losing their heritage value and position within communities.

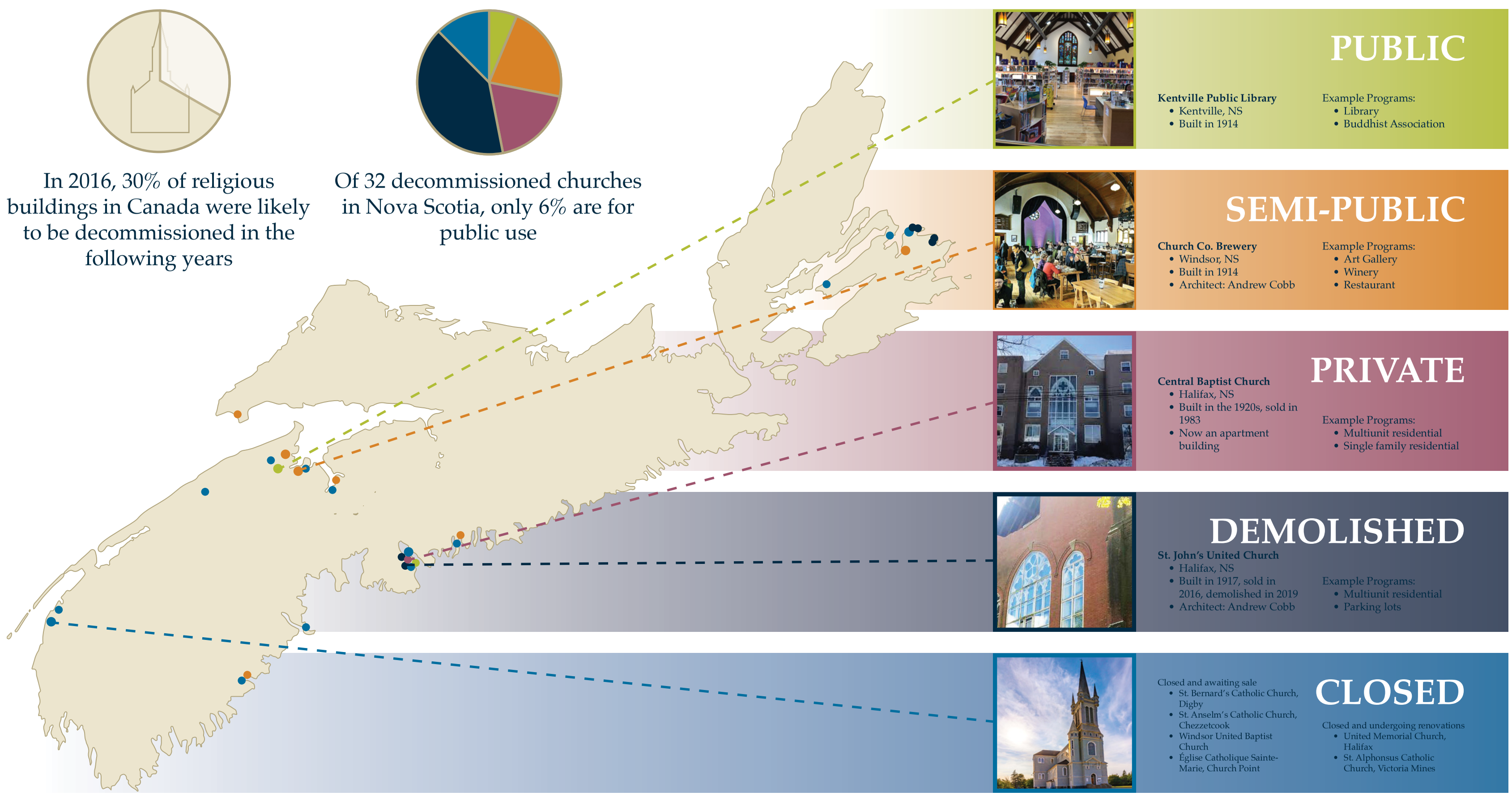
Adaptive Reuse of Churches in Canada

Churches are retrofitted to suit a wide variety of new uses in Canada. A broad range of uses can be seen Nova Scotia alone:

- Church Co. Brewing in Wolfville is located in a former Presbyterian Church;
- The Kentville library is located in a former United Church;
- Eastern Shore Gallery in Head of Chezzetcook is housed in a former Anglican Church;
- A former church on Windsor Street in Halifax now houses the Atlantic Chan Buddhist Association;
- The Central Baptist Church on Robie Street in Halifax was converted in the 1980s into an apartment building.

A crucial tenet in heritage conservation is that to conserve a building, it requires a use. Changing the use of a heritage building is often frowned upon by charters such as the *Burra Charter*, which in Article 7.1 stipulates that "where the use of a place is of cultural significance it should be retained" (2013, 4). However, the *Canadian Standards and Guidelines for the Conservation of Historic Places* specifies that:

> If the use of an historic place is part of its heritage value, every effort should be made to retain that use. Otherwise, a use compatible with its heritage value should be found. It is important to find the right fit between the use and the historic place to ensure this use will last and provide a stable context for ongoing conservation. A viable use better guarantees the long-term existence of an historic place and limits deterioration caused by human activity and the environment. (*Canadian Standards and Guidelines* 2010, 4)



Decommissioned churches in Nova Scotia (basemap from ArcGIS, 2023)

A long-lasting and sustainable use which complements the existing values of heritage place is therefore the optimal use for a church undergoing adaptive reuse. While retrofitting a church into brewery has required the removal of heritage fabric in the form of pews and other furnishing, and the addition of a significant kitchen to the church's basement, Church Co. Brewing maintains the church's function as a site of community gathering within Wolfville. Likewise, the Kentville Library and Eastern Shore Gallery maintain the public use of churches, while the Atlantic Chan Buddhist Association maintains even the sacred programming of a deconsecrated church, albeit for a different religion. Indeed, some of these new uses, such as that of the brewery, likely bring more people through the buildings' doors than they did as churches.

However, conversions of church buildings into private uses result in communities losing community space. Many churches are converted into condominiums, including Riverdale Presbyterian and Howard Park Pentecostal churches in Toronto (Bull 2016), and the Central Baptist Church in Halifax. In her master's thesis, Andrea St. James argues that "to adequately replace the loss of social space, communal gathering functions should be maintained" in retrofitted churches (St. James 2022, 10). The principle of retrofitting churches to hold new uses that foster community gathering while minimizing the loss of heritage fabric will be applied in this thesis by retrofitting the United Memorial Church in Halifax into an arts centre.

Adapting Churches into Concert Halls

Adapting churches into concert halls is a popular and effective way of keeping active churches in service and giving deconsecrated ones new uses. As churches already have a long history of housing music, which will be elaborated on in Chapter 3, they are historically and typologically well suited to being used as concert halls. Additionally, concert halls maintain churches' roles as sites of community gathering within communities, constituting a "viable" use which can help guarantee "the long-term existence of an historic place," as per the *Canadian Standards and Guidelines* (2010, 4).

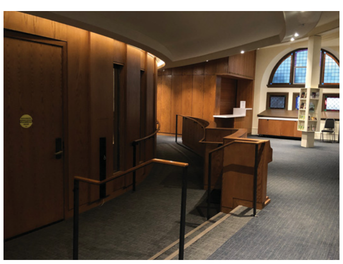
In this section, I will discuss two case studies: one of an active church being retrofitted to better house music performances, and one of a deconsecrated church in use as a concert hall.

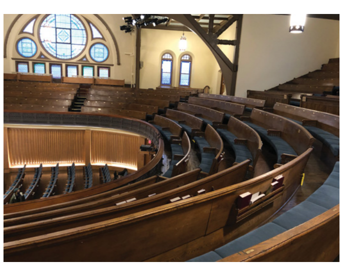
Case Study: Tafelmusik and Trinity-St. Paul's Church

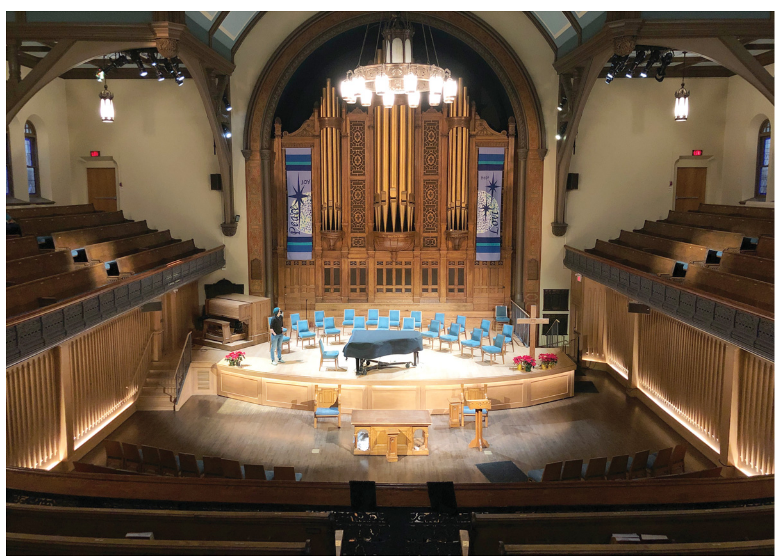
In Toronto, the acclaimed Baroque orchestra Tafelmusik has its headquarters, rehearsals, and performances in Trinity-St. Paul's United Church (TSP). Between 2013, and 2016, the Romanesque Revival church, built in 1889 and designed by Edmund Burke and Henry Langley, underwent a series of renovations to modify the sanctuary to function better as a concert hall. The success of these renovations demonstrates the symbiotic relationship between Tafelmusik and Trinity-St. Paul's in how the church provides the orchestra with performance and office space, and the orchestra provides the church with capital (Arts Build Ontario 2018, 7).

Prior to 2013, Trinity-St. Paul's lacked a proper stage, comfortable seating, and "proper acoustics" (Arts Build Ontario 2018, 7). Tafelmusik therefore considered moving to Koerner Hall, a purpose-built concert hall down the street from the church in Toronto. Faced with this possibility, the church decided to let their sanctuary be renovated into a superior space for performance, even though these renovations would change the building's functioning as a church. For example, keeping the high altar largely on level with the congregation is typical within United churches as a show of equality between ministers and lay-people, but the addition of a new stage would raise the altar above the congregation's level. Nonetheless, the church did "through a process of conversation and continual engagement" decide that agreeing to the renovations would "effectively serve their mission through the arts" (Arts Build Ontario 2018, 9).

The renovations were completed by ERA Architects, along with Anne Minors Performance Consultants and acoustician Bob Essert of Sound Space Design, and transformed the sanctuary into a "professional venue for performance and refined space for worship" (Arts Build Ontario 2018, 5). On the main floor, sound absorbing carpets were removed, and the sidewalls covered with sound diffusing wood slats. A proper stage was added, the uncomfortable pews were replaced with theatre style seating, and new glass was







Edmund Burke, Trinity-St. Paul's Church, Toronto, Canada, 1889 installed over the stained-glass windows. Additionally, a new organ screen was installed, and the choir pews removed from a semi-circular configuration behind the altar. The lobby/narthex of the church was also renovated to improve its accessibility and operation as the front of house for a concert hall.

These renovations have proved successful for both church and orchestra. In 2018, the building supported itself financially with input from increased rental revenue, "creating a sustainable business model for Trinity-St. Paul's while supporting community groups who use the space" (Arts Build Ontario 2018, 12). Arts Build Ontario writes, in conclusion, that "the relationship between Trinity-St. Paul's and Tafelmusik continues to serve as an example for other arts organizations in search of space and places of faith as a model of successful partnership built on trust, transparency and collaboration." (14).

In Halifax, St. Andrew's United Church has also strengthened its relationship with its resident orchestra, Symphony Nova Scotia, by completing renovations to its sanctuary to improve its acoustics and ability to be used as a stage. Though these renovations were not as extensive as those completed by Trinity-St. Paul's, they are still effective at encouraging arts groups to use the space for performance.

Case Study: St. Anne's Church, Indian River, PEI

St. Anne's Church, unlike Trinity-St. Paul's, has had the luck to have been well acoustically designed originally. Its acoustics are so excellent that though it was decommissioned as a Catholic church in 2009, St. Anne's has since been the site of the annual Under the Spire Music Festival, which now owns and maintains the building. As such, St. Anne's

William Critchlow Harris, St. Mary’s, Indian River, Canada, 1902

provides an example of how excellent acoustics can keep a decommissioned church in use.

The architect of St. Anne’s, William Critchlow Harris, appears from the quality his churches’ acoustics to have been well versed in architectural acoustics, as I will explore in Chapter 3. Here, it is only relevant that St. Anne’s Church has exceptional acoustics well suited to musical performance, and more akin to the acoustics of a concert hall than those of a church. After falling into a state of disrepair in the 1980s and 70s, a concert series was begun in 1987 at St. Anne’s to raise money for repairs. This series was successful and provided a steady source of income for the church, and later became the Indian River Festival, now known as the Under the Spire Music Festival. Still today, part of the festival’s mandate is to “preserve and restore [their] beautiful venue” (Under the Spire Music Festival, 2023). Unlike Trinity-St.

Paul's, which is located in downtown Toronto, St. Anne's is located in rural Prince Edward Island. Considering how much smaller an audience St. Anne's has access to, it is doubly remarkable that a music festival has kept St. Anne's from falling into disuse.

As in Trinity-St. Paul's, the symbiosis between a church and its acoustics, and a music organization, has brought stable income to heritage churches. While the music festival's organizers must receive the majority of the credit for keeping St. Anne's in use, the quality of Harris's original design must also be credited for continuing the relevance and life this church. St. Anne's proves that decommissioned churches can be kept in use, and kept in public use, through use as concert halls when their acoustics are of sufficient quality.

Diversity of Rental Organizations in Churches

The multiplicity of programs housed in churches through space rentals makes churches economically and socially supportive of their communities. Jane Jacobs writes that for cities to be economically healthy, old buildings with cheap rental spaces are essential (1961, 190). She argues that a mix of high and low yielding businesses are required, and that these different yielding businesses tend to correspond to buildings of varying ages (1961, 188). In her view, high yield arts organizations like opera houses are likely to be found in new buildings, while the "unformalized feeders of the arts," like instrument rental shops, are found in older ones (Jacobs 1961, 190). This view dates from the 1960s, but it still largely applicable in the 2020s. Today, big box stores tend to be found in new buildings, while local businesses tend to be found in older buildings. Major opera companies are likely to be located in purpose-built buildings, while smaller companies rent space in other buildings, including churches. By offering their space for rent, churches economically support not only themselves, but also small businesses in their communities.

Socially, churches can act as community centres. In a speech on the importance of church buildings (which, incidentally, was given in Trinity-St. Paul's), Natalie Bull rightly posited that "with their soup kitchens, homeless shelters and space for other charities and non-profits, places of faith are often invisible safety nets and de facto community centers" (Bull 2016). Not only do churches support their communities economically through rental space, they support their communities socially.

Trinity-St. Paul's is an excellent example of maintaining its role as a community amenity. In addition to housing a significant orchestral organization, the church also rents space to a diverse array of community organizations. A second orchestra, the Toronto Consort, is also a tenant of Trinity-St. Paul's, along with a Middle Eastern language school, a Montessori school and daycare, a socialist organization, a health coalition, a catering business, and several dance schools (Arts Build Ontario 2018, 8). This mix of organizations, along with revenue from the concert hall, has contributed to Trinity-St. Paul's financial sustainability.

The role of church buildings as community centres and homes of local organizations contributes to the social value of church buildings, and should be maintained when giving churches new uses through adaptive reuse. Housing a multiplicity of programs and plenty of rentable space will be a goal of my retrofit of the United Memorial Church.

Andrew Cobb, United Memorial Church, Halifax, 1921 (Cox Brothers 1921).

Adaptive Reuse and the United Memorial Church

The United Memorial Church in Halifax is a deconsecrated church in Halifax's North End. It was built to replace two churches lost to the Halifax Explosion on December 6th, 1917, and dedicated to the memory of the 1,800 people who were killed. As such, the church derives the majority of heritage value from its relation to the Explosion, which was the largest man-made explosion until the use of nuclear bombs in World War II. Despite its civic, provincial, and national importance (which will elaborated on in Chapter 5), the church was decommissioned in 2015. Its small congregation could not sustain which a large building, which was built to seat 700 people (Luck 2014). The operating costs of the building were too high for the congregation, with one of the major expenditures being heating, “which cost around $30,000” in the winter of 2013 (Luck 2014).

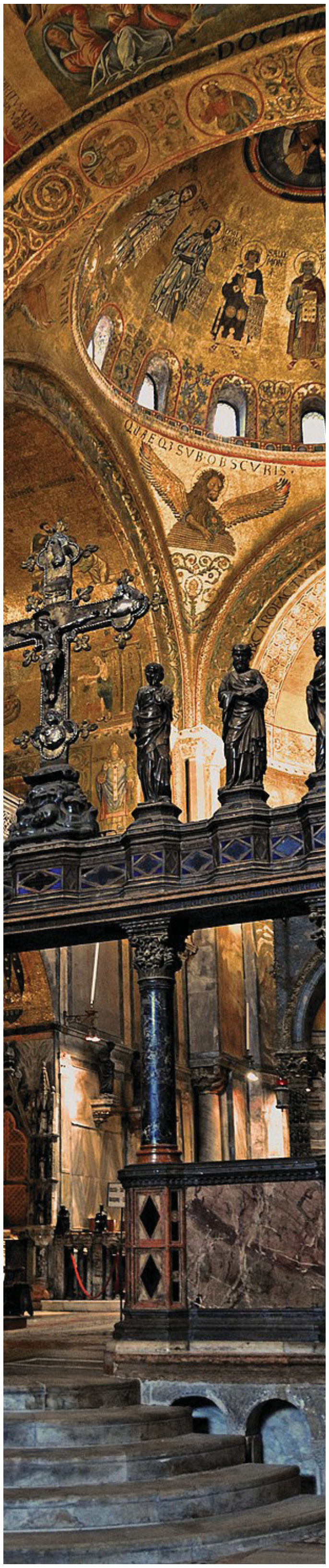
In January 2016, the church was bought by developers from Halifax, who intended to demolish the church to build a multiunit residential project. Neighbours attempted to have it listed in the City’s municipal heritage property registry in 2017. While the City did recommend the property be registered, as it passed their criteria, the owners “objected to the third party registration application at the heritage hearing and Regional Council refused to register the property as a municipal heritage property” (McGreal 2022, 2). In 2019, the United Memorial Church was listed by the National Trust of Canada as the top ten most endangered sites of that year (National Trust for Canada, 2019). Fortunately, the church has since been resold to another set of Haligonian developers, Sidewalk Real Estate, who had the building registered in the municipal heritage registry, and intend to retain the historic building. They will complete their own adaptive reuse project on this building, as advertised on their social media, though what the church’s new use will be has not been made public.

Given its rich heritage value, but inability to be sustained by its congregation, the United Memorial Church is an ideal subject for adaptive reuse..

Summary

Finding new uses for churches is an increasingly relevant problem in Canada, especially in Atlantic Canada. It is imperative that we do, so that we can maintain buildings that embody our communities, heritage, and carbon. Churches have long been sites of community gathering, and in modern society have served as community centres and homes for local organizations and charities. Ideally, these public uses should be conserved even as their original sacred purpose is lost, rather than converting the buildings to private uses. One such public aspect includes using churches as sites of gathering for performances of music, which will be explored in this thesis in the context of the United Memorial Church in Halifax.

Chapter 3: Choirs and Architecture

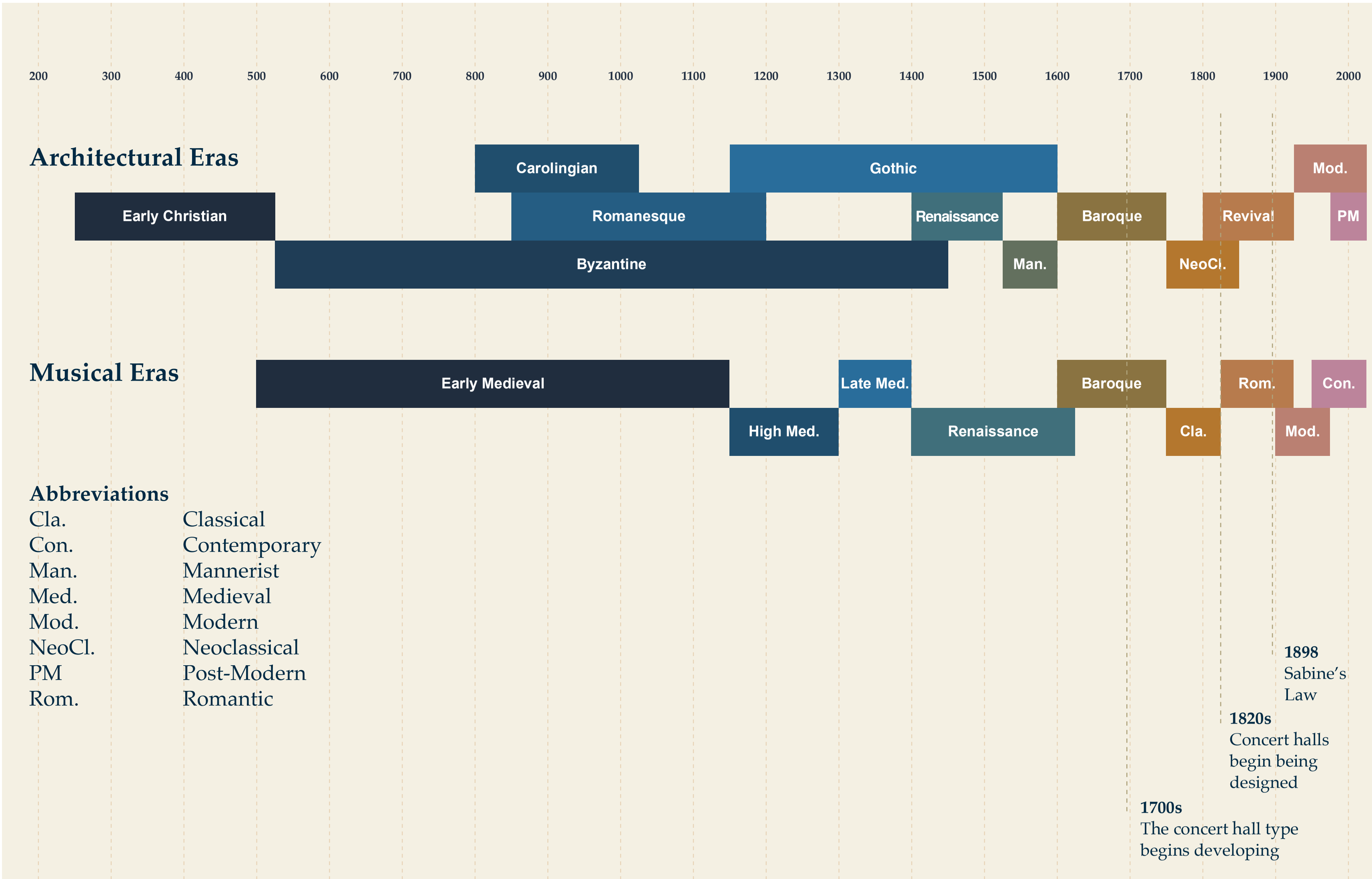


San Marco, Venice, Italy
(Jarvis 2010)

In the 21st century, we expect to hear choral music performed in venues such as concert halls, theatres, and opera houses. Specialized performance spaces like these, however, are recent developments, as compared with churches. Purpose-built concert halls began to be designed in the 1820s (Beranek 1992, 25). Prior to this, the great works of choral music were housed in churches, and have been since the Early Christian period. As such, most early choral music, encompassing works from the Medieval, Renaissance, and Baroque periods, was intended to be performed in the acoustic settings of churches, rather than concert halls.

Church architecture evolved substantially throughout these three eras, resulting in a wide array of church typologies. These churches were not designed to optimize the perception of sound, as concert halls are now. Architects had limited understanding of acoustics prior to the science of architectural acoustics being formalized in the late 1890s by Wallace Clement Sabine (Beranek 1992, 26). Furthermore, churches are designed primarily to facilitate worship, which is prioritized over effective musical performance. In this chapter, I will argue that choral church music has been performed for over 1500 years in spaces that have rarely been acoustically designed for it. Consequently, the performance and composition of choral music has adapted to suit a variety of church layouts and acoustics, which offer a greater variety of performance opportunities than those allowed by concert halls.

As no major architectural or musical treatises focus on acoustics, disparate comments on the subject must be



Comparative timelines between art, architectural, and musical eras gathered from a variety of sources in a sort of treasure hunt to discern early architects and musicians' understandings of acoustics. I will begin this chapter by outlining Pre-Sabinian architectural acoustics, and the limited degree to which churches were designed with choirs in mind, focussing especially on the design of Jacopo Sansovino and William Critchlow Harris. I will then move onto the question of how choral music was adapted to church architecture during the Medieval, Renaissance, and Baroque periods, when churches housed the greatest choral works of the age. This will include analysis of Nicola Vicentino's music theory and Adrian Willaert's composition. Finally, I will outline the development of concert halls and compare the limited performance opportunities they offer compared to churches.

Please note that Appendix B includes a list of recommended recordings of the music discussed in this chapter.

Architecture for Church Music

There are two main questions to consider regarding architectural design for music performance: how a room's features build its acoustic conditions, and how sound sources are configured in a room relative to the listeners. Choirs have long been accorded a place in churches, as the quires of Gothic cathedrals demonstrate clearly. However, the degree to which architects acoustically designed churches up until the advent of modern architectural acoustics is currently poorly understood . I will first outline pre-Sabinian architectural acoustics, then analyze the placement of choirs in churches relative to typology. I will finish this section with case studies of how Sansovino and Harris's church architecture has been designed for music.

Acoustics

The word “acoustics” is relatively new, first appearing in the 18th century (Howard and Moretti 2009, 6). Nonetheless, the science of sound has been studied since Antiquity by scholars such as Aristotle, Aristoxenes, Pythagoras, and Chrysippus, under the umbrella of physics and mathematics.

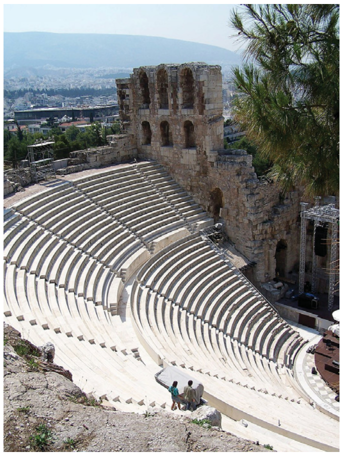
Physics of Sound

In 387 CE, Boethius summarised the acoustic knowledge of Antiquity in his treatise, *De institutione musica*. This knowledge includes the idea that sound originates from mechanical movement, is transmitted through the medium of air, and diffuses in a circular manner, similar to the spread of waves on the surface of water. This latter theory is ascribed to Chrysippus (Baumann 1990, 199). Arab scholars completed acoustical experiments between the 9th and 12th centuries, which were later translated into European languages alongside Greek and Latin works and studied by Western scholars. However, no significant innovations in acoustic theory occurred until the 17th century, when Mersenne and Galileo improved techniques for measuring sound (Baumann 1990, 201).

Architectural Acoustics

Antiquity also had knowledge of architectural acoustics, as evidenced by the design of Greek and Roman theatres. This knowledge is codified in Book V of Vitruvius’ *De architectura*, concerning the design of theatres. Vitruvius defines four types of sound reflections (Vitruvius 2006, 153; Baumann 1990, 202; D’Orazio and Nannini 2019, 253):

- dissonant reflections, which interfere destructively with subsequent sound waves;



Semi-circular Greek amphitheatre in the Acropolis, Athens, Greece (Steinle 2007).

- circumsonant reflections, which decrease the clarity of speech;
- resonant reflections, which are essentially echoes;
- and consonant reflections, which are harmonious in that they amplify and clarify speech.

Vitruvius also ascribed to Chrysippus's theory of sound propagating in concentric waves. Dario D'Orazio and Sofia Nannini call this theory "circulation theory," and argue that architectural design influenced by this produced largely round forms (2019, 252). Such forms include Greek and Roman amphitheatres, and their Renaissance imitations.

D'Orazio and Nannini also describe proto-geometrical acoustics, another Pre-Sabinian theory of architectural acoustics. This theory, which was "based on the assumption that the trajectory of sound was analogous to the sound rays reflected from a surface," has its roots in the 17th century (252), and is likely the basis for modern ray diagrams, which will be discussed in Chapter 4.

Acoustic Elements of Pre-Sabinian Architecture

Acoustics rarely feature in pre-Sabinian architectural treatises, and when they do, it is only for a few lines at a time, reflecting the fact that acoustics were not a formalized science until the 20th century. Most often, these references refer to the acoustics of theatres, not of churches, such as in Sebastiano Serlio's *Seven Books of Architecture* (D'Orazio and Nannini 2019, 254). While not connected by any treatise concerning acoustics, several architectural elements were nonetheless known by architects, clergy, and musicians to affect a room's acoustics.

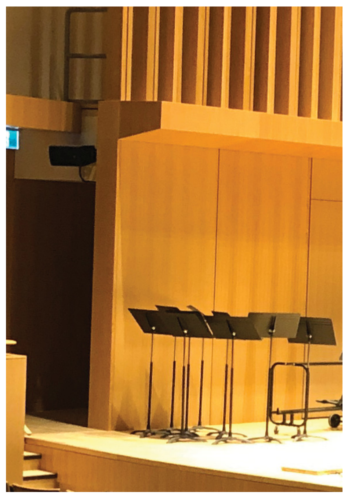
Drapery was used by musicians and clergy to absorb sound in excessively reverberant spaces (Schnoebelen 1969, 42),

Drapery in the King's Chapel, Halifax

Cornice in Il Gesu, Rome (Philippos n.d.)

Relief on walls of Il Gesu, Rome (Philippos n.d.)

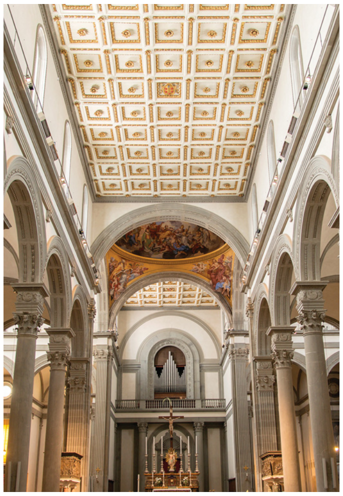
Drapery in the Strug Concert Hall, Halifax



Cornice in the Strug Concert Hall, Halifax

Relief on walls of the Strug Concert Hall, Halifax

demonstrating an awareness of the effects of material on reverberation time that anticipates Sabinian acoustics. First suggested by Vitruvius, cornices were known to reflect sound back down into a room, a "phenomenon that is still recognized by acousticians today " (Howard and Moretti 2009, 6), and recently applied in Halifax in Dalhousie University's new Joseph Strug Concert Hall. The amount of relief on walls was thought to be essential to successful acoustics, as coffers on ceilings and niches on walls could



Coffered ceiling in San Lorenzo, Florence (Burian n.d.)

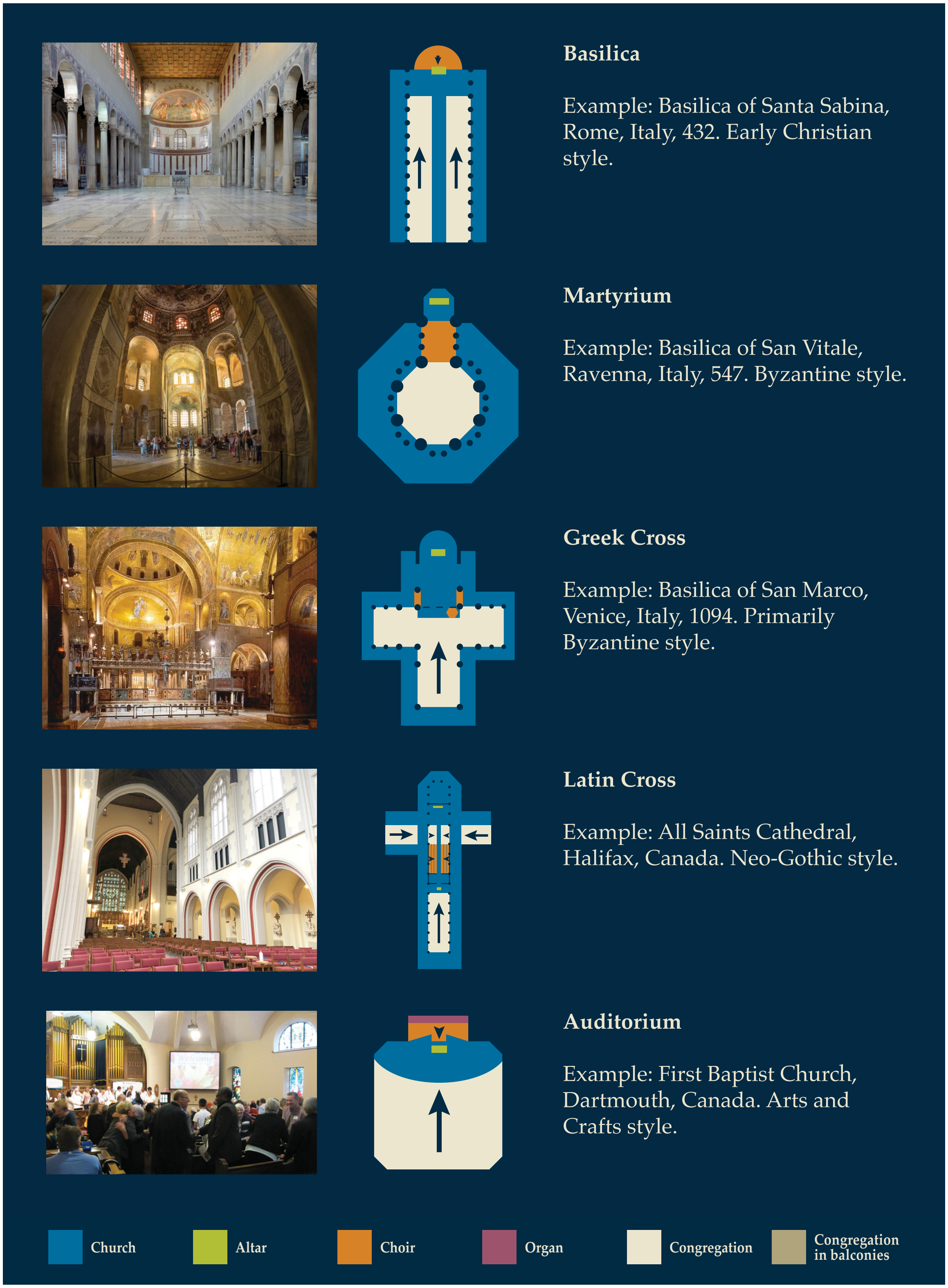
Vaulted ceiling in Il Gesu, Rome (Philippos n.d.)

interrupt and disperse unwanted reflections (Howard and Moretti 2009, 7). Again, this phenomenon is still respected in modern architectural acoustics, with David Egan writing that the side walls of auditoriums should be reflective “with as many irregularities as possible” to diffuse sound (1988, 125). Pre-Sabinian architects such as Filippo Brunelleschi were also aware that raising a sound source above a room’s floor level improves the reception of sound, as “direct sound can reach the listener better the more steeply it falls” (Baumann 1990, 203). All of these methods still stand in modern architectural acoustics, and have been applied in the design portion of this thesis.

Ceiling shape was also thought to have a significant impact on reverberation. Leon Battista Alberti, in the 1450s, argued that coffered, wooden ceilings were more suitable for use in public buildings than vaults, as vaults created conditions too reverberant to understand speech in. In 1535, the humanist Fra Francesco Zorzi added to this statement in a letter to the architect Jacopo Sansovino. He recommended that a new monastic church in Venice, San Francesco della Vigna, have a flat ceiling over the nave and a vaulted one over the quire, as he considered flat ceilings most appropriate for speech and vaults preferable for singing (Howard and Moretti 2009, 7; Navarro et al. 2009, 745).

Layouts

In the past 1500 years, churches have had a wide variety of plan types. Common church typologies include basilica, martyrium, Greek Cross, Latin Cross, and auditorium style churches. Basilica and martyrium plans have their roots in Early Christian architecture, with basilica style churches having developed from the plans of Roman basilicas



Church plan typologies

(McNamara 2011, 23). Both cruciform in plan, Greek Cross churches developed in Byzantine architecture, while Latin Cross churches are most strongly associated with Gothic (and neo-Gothic) architecture. The most modern typology listed here, auditorium style churches, reflect the increased importance of sermons since the Protestant Reformation, with the congregation arranged more closely around the altar in order for sermons to be well heard.

Choirs have occupied a wide array of positions within churches. In some churches, especially old ones, it can be difficult to ascertain the choir's intended position. Post-Vatican II reforms in Catholic churches and centuries of other renovations have vastly altered the interiors of some churches. Renovated or not, the positions of choirs reflect the liturgical ideologies of the day, and vary in popularity depending on a church's denomination. Common locations include choir balconies at the backs of churches, semi-circular pews behind the altar, and choir stalls located between the congregation and altar.

Adding to the complexity of where a choir was located in a church is whether that choir was composed of laity or clergy. In the early church, the choir was composed of clergy, and only the ordained were permitted in the highly sacred space surrounding the altar. Nowadays, church choirs are composed primarily of laity, and laity are permitted around the altar in many denominations. These dynamics between clergy and laity have a great effect on the layouts of choirs in churches. In Early Christian and Byzantine churches, the location of the choir and of the clergy appears blurred, likely because they were one and the same. Some monastic churches include retroquires, where the quire is located behind the altar, and screened off from view from the laity.

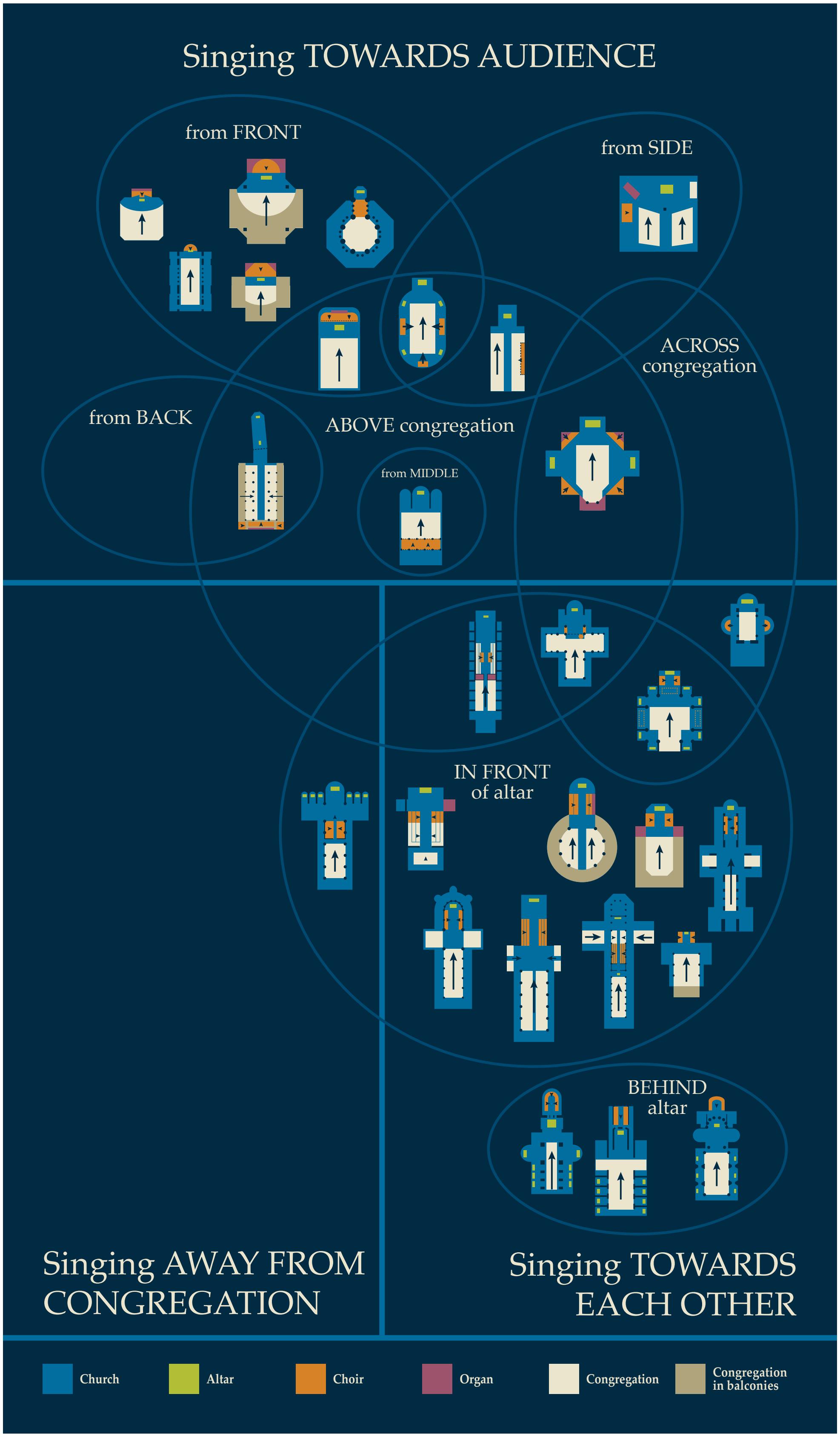
In Baroque churches that employed laity as the choir, such as St. Thomas's, Leipzig, where J.S. Bach worked, the choir was located in the back balcony, far outside the sacred bounds of the chancel. However, in modern auditorium style churches, the choir returns to being located behind the altar, reflected how the altar area is no longer restricted. These latter churches are especially well suited to being adapted into concert halls, as their plans prioritize seeing and hearing sound from the altar area, which can then easily be retrofitted into a stage.

Typology of Quires

Though there are many typologies of churches by plan type, I have found no study of church plans relative to the location of the choir. As such, I have attempted to establish my own typology of quire types, shown on the next page.

My typology consists of three main categories according to which direction the choir sings relative to the congregation. These categories have then been subdivided according to the choir's orientation relative to the high altar.

- Churches where the choir sings towards congregation:
    - From the front;
    - From the back;
    - From the side;
    - From the middle;
    - From above;
    - And across the congregation.
- Churches where the choir sings towards each other:
    - From behind the altar;
    - From in front of the altar.
- Churches where the choir sings away from the audience:
    - From in front of the altar.



Quire typology diagram

Churches in typology chart

Early Christian

San Vitale, Ravenna, Italy

Byzantine

San Marco, Venice, Italy

Hagia Irene, Istanbul, Turkey

Gothic

King's Chapel, Cambridge, United Kingdom

Thomaskirche, Leipzig, Germany

Santa Maria Gloriosa dei Frari, Venice, Italy

Westminster Abbey, London, United Kingdom

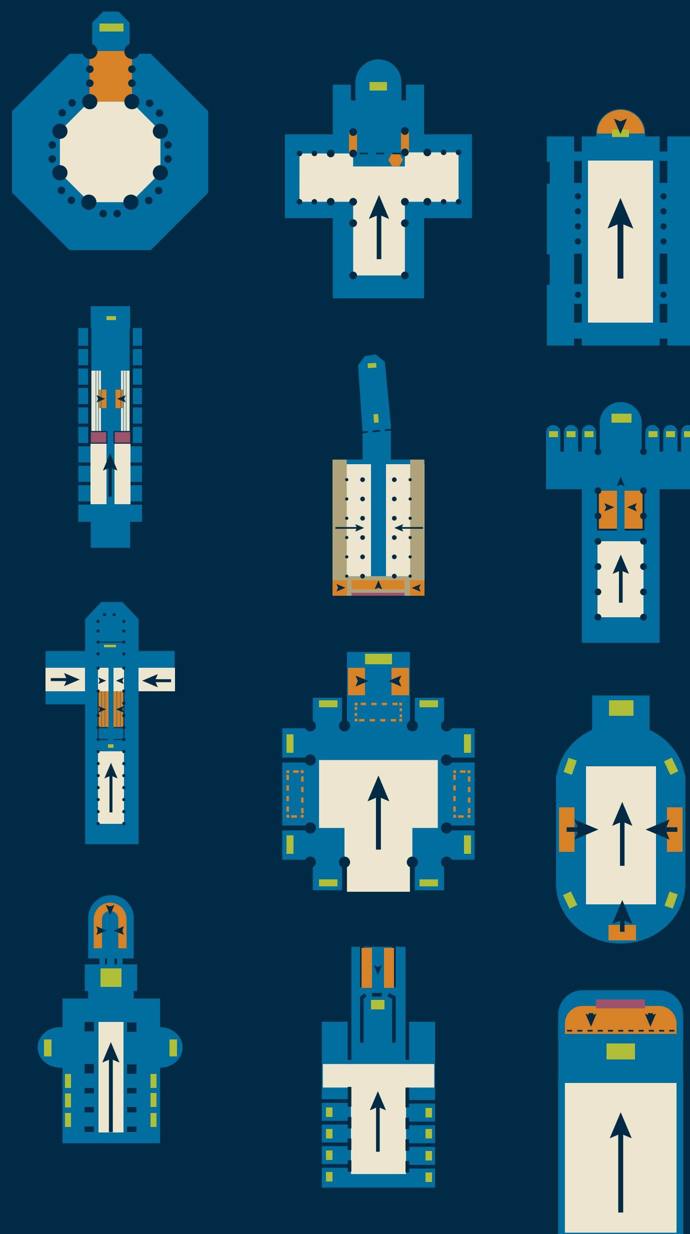
Renaissance

San Martino, Venice, Italy

Incurabili, Venice, Italy

San Giorgio Maggiore, Venice, Italy

San Francesco alle Vignola, Venice, Italy



Index of churches in the previous typology chart

Churches in typology chart, cont.

Ospedaletto, Venice, Italy

San Michele in Isola, Venice, Italy

Mendicanti, Venice, Italy

St. Paul's, London, United Kingdom

Baroque

Muri Abbey, Muri, Switzerland

Neoclassical

St. George's Round Church, Halifax, Canada

Gothic Revival

St. David's, Halifax, Canada

All Saints Cathedral, Halifax, Canada

St. Andrew's, Halifax, Canada

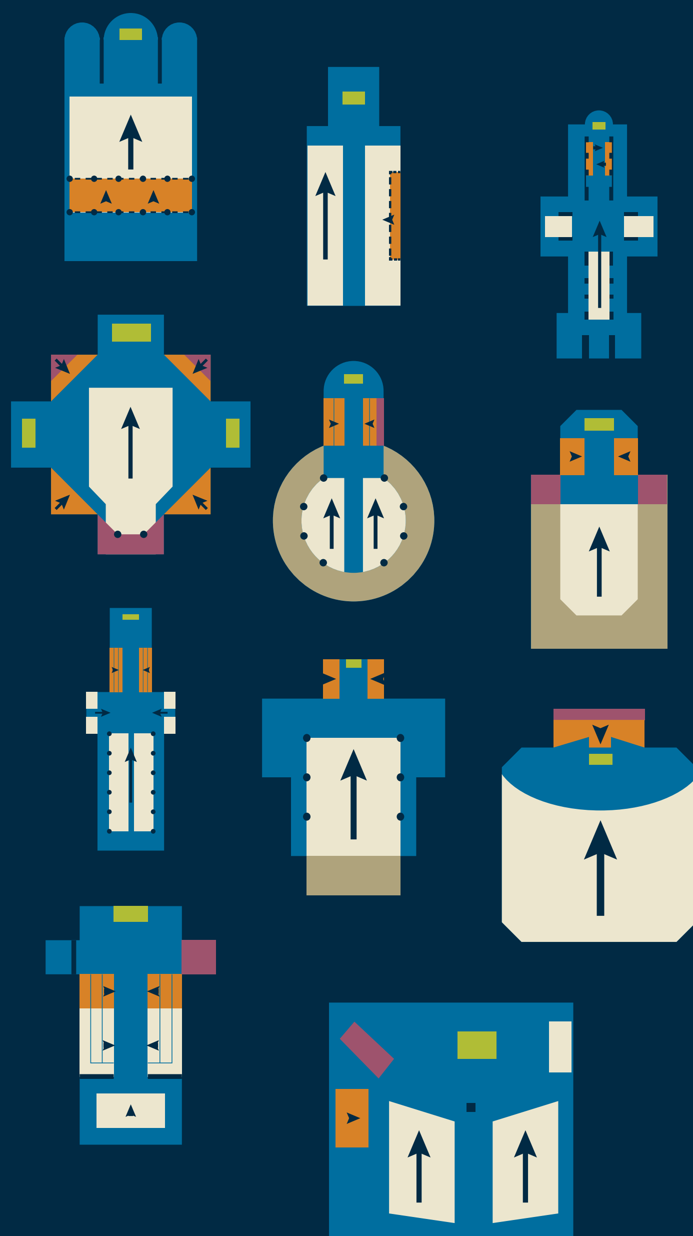
United Memorial, Halifax, Canada

First Baptist, Dartmouth, Canada

King's Chapel, Halifax, Canada

Modern

St. Peter's, Klippan, Sweden



Index of churches in the previous typology chart

It should be noted that this typology bears a bias towards Venetian and Haligonian churches. The Venetian churches are all drawn from Deborah Howard and Laura Moretti's book *Sound & Space in Renaissance Venice*, while Haligonian churches have been included due to my own familiarity with them. A more detailed typological diagram is also included in Appendix C.

Some churches fit into these categories in a clear-cut fashion, while others do not. As such, none of these categories are mutually exclusive. For example, the Church of the Incurabili in Venice has choir balconies at the back and sides of the church. I have categorized it as "singing towards the congregation," "from the back," "from the side," and "from above."

There are a few patterns to be gleamed from cross-referencing a church's style, plan type, quire type, and denomination, as in Appendix C. Gothic and Anglican churches are most likely to have a choir which faces each other, located in what's called a divided chancel, where the choir is divided between the two sides of the chancel. Retroquires appear to be a uniquely Catholic phenomenon. Most important to this thesis, however, is the diversity of spatial relationships between the choir and the congregation.

Acoustic Design by Pre-Sabinian Architects

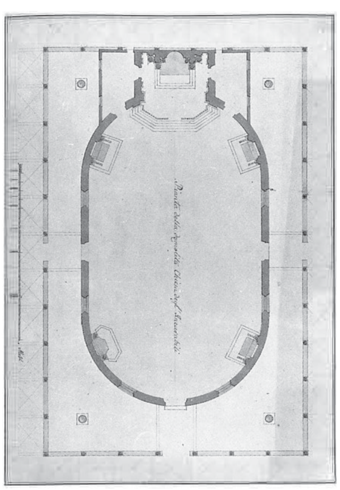
Given the lack of treatises and primary sources on the matter, it is difficult to determine the degree to which pre-Sabinian architects purposefully designed acoustics, and with what goal in mind. I will discuss two architects who designed acoustically successful spaces prior to the advent of modern architectural acoustics: the Italian Renaissance architect, Jacopo Sansovino (1486-1570), and Canadian

Victorian architect, William Critchlow Harris (1854-1913). Though Sansovino designed multiple acoustically successful churches and worked alongside musicians, the degree to which he purposefully applied acoustic design is unclear. Harris, an amateur musician himself, explicitly applied acoustic theory to his church design in the era immediately preceding Sabinian acoustics.

Case Study: Jacopo Sansovino

Sansovino has already been mentioned in this thesis as the architect who received the letter about the appropriate ceiling types relative to the intended acoustic use of San Francesco della Vigna. Against Zorzi's advice, this church was built with a vault, for reasons unknown. Nonetheless, his receipt of Zorzi's letter and the acoustic success of his other church designs and modifications suggest that Sansovino was knowledgeable about acoustic design. Such other churches include the Venetian churches of the Incurabili, San Marco, and San Giuliano.

Properly known as the Church of the Santissimo Salvatore at the Hospital of the Incurabili, this church was the chapel of one of Venice's hospitals, which also housed orphaned children. The Incurabili had an international reputation for "exceptionally favourable acoustics" for the performance of choral music (Howard and Moretti, 164). It was oval in plan, with a coffered ceiling and two singing galleries. The Incurabili's acoustic behaviour was compared to that of stringed instrument, with the ceiling acting "as the sounding board and the roof space as the belly of the instrument" (165). However, there is no evidence that Sansovino purposefully designed the Incurabili to have good acoustics for musical performance, and Howard and Moretti suggest



Plan for the Incurabili
(Wcowich-Lazzari, 1989)

Balconies designed by Sansovino in the chancel of San Marco. *Ceremonia della consegna del pielo e dello stocco, donati del pontefice Alessandro VIII a doge Francesco Morosini il Peloponnesiaco; fatta nel presbiterio della Basilica il 7 maggio 1690*, 1690 (Hammond 2012, 254).

that its excellent acoustics may have resulted “accidentally” from the limitations of a tight site and budget (171). Though it was demolished in 1831, the Incurabili’s acoustics were reconstructed digitally for Howard and Moretti’s study of Venetian churches, which confirmed its excellence.

Sansovino was the chief architect and superintendent of buildings for the Procurators of San Marco from 1529 to his death in 1570, and was tasked with maintaining and making modifications to the Byzantine structure. Among these modifications were the addition of two singing galleries on either side of the chancel, just inside of the roodscreen. While the first gallery was built in 1536-37 as a matter of practicality, the second was built opposite the first between 1541 and 1544 (36). The timing of this second construction is important, as the choir master of San Marco, Adrian Willaert, was composing a set of psalms for divided double choirs (coro spezzato) at the same time. Given that Sansovino and Willaert, who worked at San Marco from 1527 until his death in 1562, worked for San Marco simultaneously for 33 years, it is probable that they knew each other well and that the second balcony could have been designed for use in Willaert’s coro spezzato music. Additionally, Howard and Moretti determined these balconies to be acoustically excellent for the performance of Willaert’s music. The acoustician associated with their study, Raf Orlowski, declared the sound “perfect” (39). The galleries, set into the walls of the chancel, mixed the singers’ voices together before projecting their sound out into the chancel where the doge sat (39). As a result, their sound was well-blended, directional, and clear, with a pleasant reverberation (39).

By contrast, San Giuliano is a parish church in Venice with a small volume and consequently short reverberation time

Jacopo Sansovino, San Giuliano, Venice, Italy, 1554 (Kamaras 2017).

(153). This short reverberation made the church’s acoustics excellent for complex, melismatic polyphony, the sounds of which would be blurred and lost in a highly reverberant church, such as San Marco or San Francesco della Vigna. Howard and Moretti write that if Sansovino purposefully designed the church’s acoustics in such a fashion, he demonstrated “sensitivity to the musical developments of the age” (160). Additionally, they note that “the fascinating question” San Giuliano is “whether Sansovino deliberately sought a less resonant acoustic in order to create a space adapted to the new coro spezzato music published by Adrian Willaert in the same years” (159).

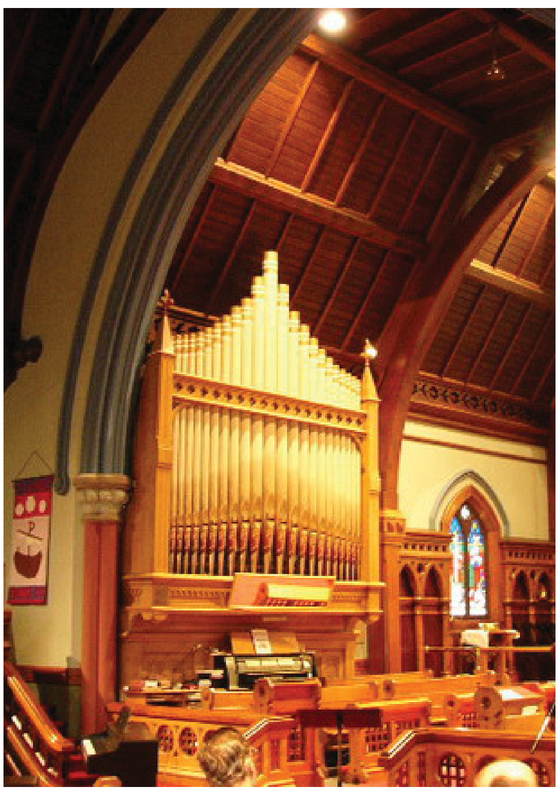
Though Sansovino produced multiple acoustically successful spaces that reflect “sensitivity to the musical developments of the age”, there is no evidence that he purposefully designed these spaces with acoustics in mind (160). However, his connections with Willaert put him in an excellent position to be up to date with musical trends, as reflected in his architecture. If Sansovino did cognisantly design the acoustics of these three churches, their success demonstrates that he was an accomplished acoustician.

Case Study: William Critchlow Harris

By contrast, it is a known fact that William Critchlow Harris designed churches with acoustics in mind. Harris was a Canadian architect who worked largely in Prince Edward Island and Nova Scotia. An amateur musician, Harris sang in Anglican church choirs (Tuck 1978, 30-31) and played violin (100), which gave him first-hand experience of acoustics. He employed violin construction techniques to amplify sound in his church designs, such as using wood panelling to intensify sound, “as the front and back of a violin intensify the sound produced by the reverberating string of the instrument” (74). In these panels, he was particular about his use of different woods for acoustic effect, and thought spruce wood to be especially resonant and appropriate as a ceiling finish (108, 74). He also used recessed windows, cross joists in ceilings, and wooden groin vaults to diffuse sound. In St. Anne’s Church, previously mentioned in Chapter 2, Harris employed groin vaults to diffuse sound and wood panelling to amplify and reflect sound. There is an audible reverberation in St. Anne’s, but not a long one. Vocal sound is richly blended, and more akin to a concert hall’s acoustics than a church. His designs for St. James in Mahone Bay (completed in 1887) and St. Paul’s in Charlottetown (completed in 1896) have similarly excellent acoustics.

Harris was familiar with the different levels of reverberation suitable for both speech and music, as well as ray diagrams, which are described in Chapter 4. While in competition with Ralph Adams Cram to win the design for All Saints Cathedral, Halifax, Harris used ray diagrams to argue for the acoustic superiority of his design over Cram’s. Unfortunately for Harris, who had desired to design a cathedral in Halifax for decades, Cram won the commission. Indeed, Cram’s acoustics are very reverberant and almost echoey. Harris criticized how poor the finished cathedral’s acoustics are for speech, but also admitted that Cram’s cathedral is “splendidly adapted to music” (199). I sing regularly in this cathedral, and can confirm Harris’ assessments of its acoustics. Indeed, All Saints Cathedral is the eponymous “building that sings” after which this thesis is titled.

Harris’s acoustic design is masterful and effective, but what is especially intriguing is how he learned architectural acoustics. Was Harris taught acoustic design by mentors or instrument builders, or did he teach himself acoustics from books or his own experiments? The churches I have listed by him range in completion dates from 1887 to 1902; Wallace Clement Sabine derived Sabine's Law in 1898 (Beranek 1992, 26). Harris could potentially have applied Sabinian architectural acoustics to his later designs, but not his earlier ones. If Harris, a moderately well-known architect from Prince Edward Island, could master acoustics to such a degree before Sabinian architectural acoustics were popularized, Victorian architects must have had better knowledge of architectural acoustics than they are typically given credit for.



William Critchlow Harris, St. James Anglican Church, Mahone Bay, Canada, 1887 (Musique Orgue Québec)

William Critchlow Harris, St. Paul's Anglican Church, Charlottetown, Canada, 1896 (Meier 2006)

As I have shown, determining how church architecture has been adapted to suit early choral music is a complicated process. Pre-Sabinian architects did have knowledge of architectural acoustics, but it is difficult to determine whether they intentionally designed church acoustics at all, much less to enhance music performance. However, there is an equally interesting question to ask regarding this topic: how has choral music been adapted to the acoustic conditions of churches?

Music for Church Architecture

Choirs have been housed in churches for the past 1500 years, yet few of these churches have been adapted acoustically for the benefit of choirs. As such, choral music has had to adapt to the acoustic and architectural conditions it has been dealt. These conditions are widely varied, from the dry reverberation of small, wooden parish churches to echoing stone cathedrals, and from simple choir stalls behind the altar to multiple choir galleries arrayed throughout a nave. Barry Blesser and Linda-Ruth Salter write that “when a musical space is considered to be an extension of musical instruments … it becomes a tool to be used by composers, musicians, and conductors” (2007, 7). Choral music has had to mitigate the negative effects of church acoustics, but also has used these spaces to add or increase musical effect. As with architecture, there are no musical treatises that address acoustics thoroughly; rather, discrete comments relating to acoustics must be gathered together from an array of sources in a sort of treasure hunt .

As I did while considering how architecture has been adapted for choral music, I will divide this section into how choral music has dealt with acoustic issues (largely relating to reverberation), and how it has dealt with church layouts. This section will focus largely on Early Music, or music from the Medieval, Renaissance, and Baroque periods, as these periods predate concert halls designed specifically for music, and therefore more successfully show the adaptations composers made to accommodate varying acoustics.

Acoustics

Reverberation can pose many issues to music, while also complementing it. Excess reverberation leads to a loss of clarity; both notes and words can quickly become unintelligible. As notes bleed into each other, reverberation "can produce a blending of sequential notes, almost like chords" (Blesser and Salter 2007, 3). This can increase the number of clashes, requiring harmonic simplicity and carefully orchestrated key changes on the part of music. The earliest extant form of Western choral music, plainchant, is well adapted to reverberant environments.

Byzantine church of Hagia Eirene, Istanbul, Turkey (Gryffindor 2007)

Gothic style Lincoln Cathedral, Lincoln, United Kingdom. (Cc364, 2018)

Plainchant

Plainchant is rhythmically simple and monophonic, providing its lyrics the greatest chance of being heard. Blesser and Salter argue that the “slow, monophonic” style of Gregorian chant, a form of plainchant, became “the vocalization of choice” in the early church as “an inevitable consequence of the high reverberance of most cathedrals and monasteries” (2007, 93). Plainchant is still in regular use in churches today, and remains strongly associated with its original acoustic. Even non-musicians associate Gregorian chant with reverberation and cathedrals, with Juhani Pallasmaa writing that “in the silence of the Gothic Cathedral we are reminded of the last dying note of a Gregorian Chant” (2005, 51). Blesser and Salter point out that chants are “so tightly linked to their original spaces, that in 1994, when the Benedictine monks of Santo Domingo de Silos recorded Chant, one of the best-selling albums of Gregorian chant music, they selected the same space their brethren has used some thousand years before” (2007, 93).

Polyphony

During the late Medieval period and into the Renaissance, monophonic music grew increasingly complex, developing into polyphony. As was typical of the Renaissance, composers and humanists sought to codify the rules of music in treatises. Among these treatises is Nicola Vicentino’s 1555 publication, *L’antica musica ridotta alla moderna prattica*. Among the many aspects of music touched in the treatise, Vicentino classifies three genres of music (diatonic, chromatic, and enharmonic music) in relation to their appropriate audience type, thereby setting up a dichotomy between choral music for churches and chambers.

Vicentino argues that diatonic music should be "sung at public festivals in communal places for the benefit of coarse ears," while chromatic and enharmonic music should be "used to praise great personages and heroes for the benefit of refined ears amid the private diversions of lords and princes" (Schiltz 2003, 65). Katelijne Schiltz argues that by classifying genres of music relative to the "social make-up of the intended audience" (2003, 65), Vicentino inherently also classifies these genres of music relative to the expected acoustic conditions and building that the performance of this music would take place in. Public performances in Vicentino's day would be sung by choirs and occur in churches with long reverberation times, while private performances would be sung by solo ensembles in private chambers with short reverberation times.

Schiltz dissects Vicentino's recommendations for the composition and performance of diatonic and of chromatic and enharmonic music to highlight the differences between them, which demonstrate Vicentino's "clear awareness of the deep impact that the performance place and the number of singers have on the rendition of music" (67). Vicentino argues that enharmonic and chromatic music require a softer dynamic to catch their harmonic "subtleties," making them best suited to chamber performances, rather than church performances (67). Likewise, enharmonic music should be performed in spaces with low reverberation, as "church acoustics cannot render quick notes, as they would become imperceptible" (71). These recommendations develop a dichotomy of compositional techniques to suit particular acoustic conditions.

Interestingly, Vicentino demonstrates an awareness of the connection between a room's volume and its reverberation

Location	Church	Chamber
Audience	Public	Private
Language	Latin	Italian
Number of singers	Choir	Solo ensemble
Volume (loudness)	Louder	Softer
Tempo	Slower	Faster
Intonation	Simpler harmonics	More complex harmonics
Volume (spatial)	*Larger*	*Smaller*
Reverberation Time	*Longer*	*Slower*

Vicentino's dichotomy, as outlined by Schiltz, with architectural additions in italics

time. He anticipates churches to have large interior volumes, as a louder sound is required to fill the volume of a church than that of a chamber. He also plans for such large churches to have high reverberation times, as reflected in his comments concerning tempo. In such, Vicentino almost anticipates Sabine's Law, developed nearly three and a half centuries later.

Contemporary Choral Music

Contemporary choral music also takes into account the amount of reverberation in its intended performance location. In his piece *Into Thy Hands*, written in 1996 for performance in the Cistercian Abbey of Pontigny, France, Dove incorporates long rests for reverberation to dissipate in. Dove writes that he "imagined that the echo would be part of the piece, and set [the first part] spaciously, allowing for the sound of each phrase to reverberate" (Dove 1996). These long pauses add a contemplative and calm sense to the piece, reinforcing the text's message, which is two prayers of St. Edmund. Additionally, the scale and mode of the piece are consistent throughout, which Dove did purposefully to maintain harmonic clarity in the Abbey's reverberant acoustics (Lapwood 2020).

Pontigny Abbey, Pontigny, France (Finot 2011)

Choir in King's College Chapel, Cambridge, United Kingdom (acambridgediary 2022)

Many of the above strategies to accommodating church acoustics in the composition of choral music serve to mitigate the negative effects that reverberation can have on the textural and harmonic clarity of choral music. Plainchant, Vicentino, and Dove all employ harmonic simplicity to maintain musical clarity. Plainchant is often sung slowly in reverberant settings, which Vicentino also advises for performing diatonic music in churches, while Dove incorporates long pauses in his music. Though Vicentino and Dove may have been the most explicit about how they accommodated acoustics in composition, they are by no means the only two composers to have done so. While it may seem that acoustics constrain composition, they also offer opportunities, as Dove demonstrates with *Into Thy Hands*. The use of church layouts for musical effect is another area where architecture and acoustics offer opportunities to composers.

Andrew Cobb, University of King's College Chapel, Halifax, Canada, 1928

Layout

As I have already shown, churches have a wide array of plan types, with choirs occupied varying positions within churches. These positions offer compositional opportunities for musicians to profit from.

Antiphony

Churches with divided chancels are especially common in Gothic and neo-Gothic architecture. In Gothic churches, these chancels were often occupied by monks, who would have formed the choir. A common practice for psalm singing is to alternate verses from side to side of the divided chancels, called antiphony. Carver writes that antiphony is "one of the pillars of Western chant; antiphonal performance of psalms and canticles makes up a large proportion of the Latin Office” (1988, 14).

Within polyphonic music, antiphony is often used by composers to give a sense of dialogue between choirs, or to add variety. The English Renaissance composer Orlando Gibbons uses antiphony to great effect in his double choir anthem, *O Clap Your Hands*, with the two choirs singing the line “o sing praises” in alternation. This use of antiphony increases the piece’s drama and excitement level, as evidenced in the Cambridge Singer’s recording of the piece, listed in Appendix B. In Jacob Handl’s double choir setting of *Duo Seraphim*, first published in 1587, the two choirs echo

Orlando Gibbons, *O Clap Your Hands*, bars 64-67

Tenor soloists singing Monteverdi's *Duo Seraphim* in San Marco (Monteverdi Choir 1989)

each other with slight variations. This is likely a play on the piece's first line, which translates to "two seraphim cried to one another" (CPDL, Duo Seraphim). Claudio Monteverdi employs the same strategy in his setting of the text from his 1610 *Vespers*, but with two tenor soloists instead of two choirs. In their filmed performance of the *Vespers* in San Marco, where Monteverdi worked, the Monteverdi Choir uses architecture to accentuate the text even more by locating the two tenors up in San Marco's twin organ balconies, as though they were seraphim up in the heavens (Monteverdi Choir 1989).

While antiphonal, double choir was popular across Christian denominations during the Renaissance, it has been enduringly embraced by the Anglican church, with modern compositions by Charles Wood, C.H.H. Parry, and Benjamin Britten adding to the Anglican Church's stash of double choir music. This parallels the popularity of divided chancels in Anglican church architecture. As this is the quire layout most suitable for the liturgical performance of double choir music, it is likely that the Anglican tradition of divided chancels and of antiphony have mutually supported each other.

Polychoral Music

While double choir music employs two choirs, polychoral music can employ two to ten choirs, and also developed during the Renaissance with antiphony as one of its roots (Carver 1988, 41). When these multiple choirs are spread throughout a church, architectural space implicitly becomes part of the musical effect, as the audience can hear the choirs responding to each other across the space. German Baroque composer Heinrich Schütz's triple choir piece, *Saul, Saul, was verfolgst mich?* provides an excellent example of this. With text drawn from the Conversion of St. Paul, all three choirs alternate crying out "Saul, Saul," in quick succession, increasing the sense of urgency and torment. With a surround sound experience of the choirs arrayed around the audience, the audience feels quite railed upon, as Saul would have in the text.

In addition to adding musically to performances, Anthony Carver argues that polychoral composition was employed by composers to increase perceived volume. He stipulates that the basic principle of stereophony is "that to fill a hall with sound it is not necessary to fill it with musicians but to use two or more separated sound sources" (Carver 1988, 6). This technique enabled composers to increase the perceived volume of their compositions without actually increasing the number of singers. Though this principle is modern, Vicentino anticipates it during the Renaissance:

> In churches, and in other broad and spacious places, music composed for four voices makes little impression, even [though] there might be many singing each part. However, for variety, and for the necessity of making a big sound in such

Heinrich Schütz, *Saul, Saul, was verfolgst mich?*, bars 67-70

> places, one can compose [? For two choirs] Masses, Psalms, and Dialogues. (Carver 1988, 6)

Vicentino furthermore adds that “to make the greatest sound one could even compose for three choirs” (Vicentino, quoted in Carver 1988, 7), clearly demonstrating how stereophony can be used to increase perceived sound where a single choir is insufficiently loud.

Though the musical effects of dialoguing and stereophony could be invaluable, spacing choirs so far apart from each other is not without its difficulties. Considering that sound only moves at 343 m/s, choirs spaced far apart from each other could easily become out of time. Additionally, the pitch of reverberant sound can seem to go flat or sharp as it travels through a large, reverberant building. In terms of physics, I have found no explanation for this phenomenon; neither reverberation nor distance affect pitch. Nonetheless, it is a phenomenon that multiple professional musicians have related to me, so this phenomenon will be considered, regardless of the physical mechanism behind it.

In San Marco, Adrian Willaert developed compositional strategies to mitigate issues of tempo and pitch between spatially distanced choirs. Firstly, he arranges his polychoral music so the two choirs rarely sing simultaneously, negating the development of timing issues between the choirs. Secondly, he uses cadential overlaps as the choirs transition to solidify the entering choir’s tuning.

Cadential overlaps

Music theorists Gioseffo Zarlino and Nicola Vicentino both detail the technique of overlapping choirs during transitions from one choir to the next. Vicentino writes the following advice:

> When one wishes to pause, and to finish the first phrase of the first choir, one arranges that the second choir takes over in the middle of the final note of the aforementioned first choir, in unisons or octaves with all the parts. (Carver 1988, 8)

This enables the tuning to be correctly transferred between choirs, as “the voice that is singing will be a sure guide” for the following choir (Schiltz 2003 72, quoting Vicentino). Musicologist Anthony Carver notes that these overlaps also serve to maintain musical continuity (1988, 8). Nonetheless, these guidelines facilitate the successful transition between choirs.

Both Vicentino and Zarlino argue that it is especially important to overlap the bass parts during these transitions. Carver refers to these bass overlaps as “spatial bass parts.” Vicentino advises that “when planning for two or three choirs to sing at the same time, it is advisable to make the basses of two or all three choirs agree with one another,” writing that basses should enter at the unison, octave, or major third from the preceding bass part in order for the “true bass” to be perceived (Schiltz 2003, 72).

Carver argues that spatial bass parts reveal whether or not a piece was intended to have been performed with the choirs spatially separated or not. Vicentino and Zarlino both write that when the overlaps are written with the bass parts overlapping at the unison, octave, or major third, then “the choirs will also be able to sing separately one from the other … if the parts are distant [from each other]” (Carver 1988, 9-10). According to Carver, Willaert’s treatment of bass parts imply a spaced performance. Indeed, his music exemplifies the use of overlaps between choirs during transitions. In Willaert’s double choir setting of *Laudate Pueri* from 1555, there are fourteen transitions between choirs. In thirteen

Overlaps between choirs in Willaert's *Laudate pueri* à 8.
Entering basses begin in unison with the exiting basses.
(Willaert [1555] 2017, 102)

Octave

Major third

Outlying overlap, where the basses enter
at the major third, rather than the unison.
(Willaert [1555] 2017, 106)

of the transitions, the basses enter in unison with the preceding basses. The outlying overlap, which occurs in bar 94, has the bass enter a major third above the other bass. Zarlino credits Willaert with this method of composing bass parts, writing that Willaert's technique allows choirs which are "placed at some distance from each other" to remain consonant (Carver 1988, 10).

Non-Venetian Polychoral Music

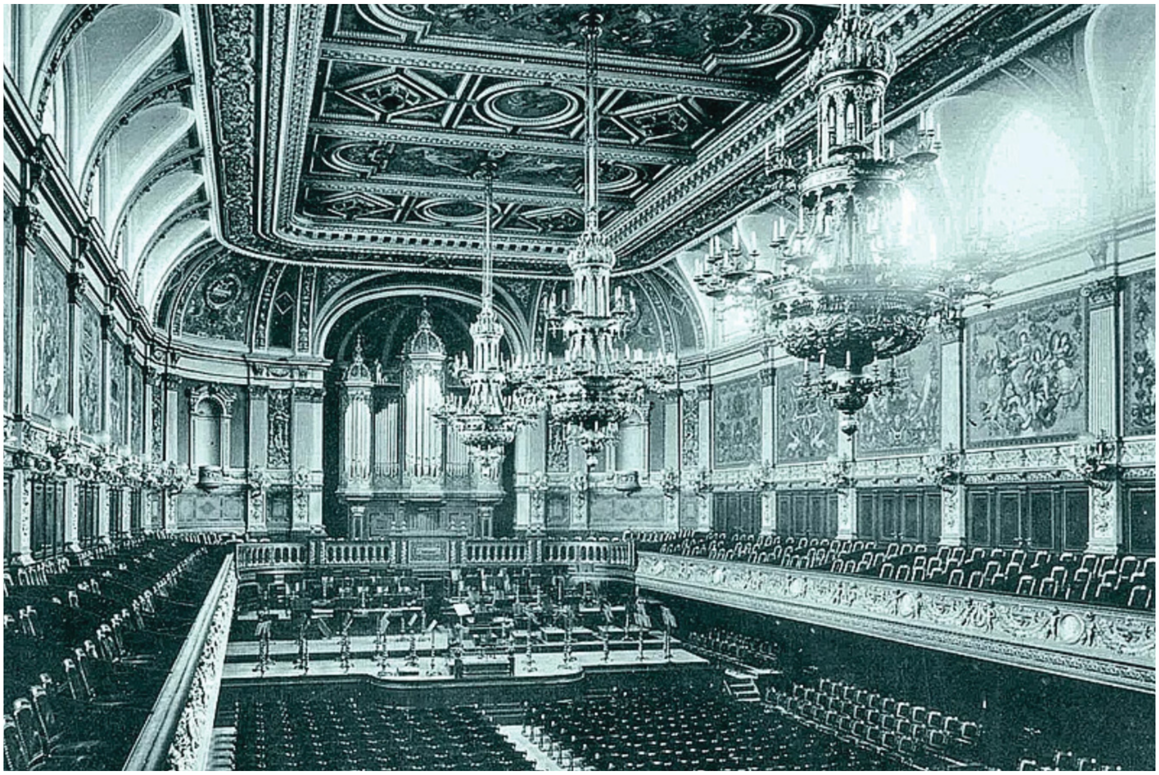
Venetian music occupies the lion's share of scholarship on the interrelation of polychoral music and architectural space. This thesis reflects that trend, focussing much on the architecture of Sansovino and composition of Willaert, both of whom worked in San Marco, and the theories of Vicentino, whose works were published in Venice. However, plenty of polychoral music was written in other parts of Italy and Europe, especially in what is now Germany. John Guzik suggests that "many of the same principles used in investigating the use of space at St. Mark's can be applied to similar examples of music from alternative locations" (2020, 19). However, it is difficult to link other polychoral composers such as Michael Praetorius, G.P. da Palestrina, Orlando di Lasso, Heinrich Schütz, or Thomas Tallis to specific buildings and acoustic conditions, as Willaert is linked to San Marco. Scholarship of Venetian music is likely so successful because it can be traced to specific situation and building. Here, interdisciplinary studies between musicologists and architectural historians would likely be profitable to both academic subjects to illuminate how choral music and architectural space have complemented each other outside of Venice.

Prior to the advent of modern architectural acoustics, churches have rarely been designed with the acoustic needs of choral music in mind, though the designs of Jacopo Sansovino and William Critchlow Harris prove an exception to this. Choral music has instead adapted to church architecture, using the acoustics and layouts of churches for musical effect, as in double choir and polychoral music. As such, architecture has influenced the development of choral music. In some respects, such as the design of Gothic quires or Sansovino's double balconies, architecture has been influenced by music, though to what extent is unclear. This extent is, however, very clear in the design of concert halls, whose sole purpose is to house musical performances.

Concert Halls

Concert halls are the main location we expect orchestral and choral music to be performed in. They are purpose built for musical performances, and nowadays, are carefully designed by architects and acousticians to optimize the propagation of sound in them.

Dario D'Orazio and Sofia Nannini write that the "first music rooms of the modern age " were designed in the early sixteenth century (2019, 252). Between the seventeenth and eighteenth centuries, secular music transitioned from being performed in the music rooms of palaces to small theatres, such as the Alte Residenz Theatre in Munich (Beranek 1992, 25). While theatres tended to follow a more circular or oval design, still influenced by circular Greek and Roman theatres (D'Orazio and Nannini 2019, 252), palatial music rooms were typically derived from rectangular ballrooms (Beranek 1992, 25). The first halls built purposefully for concerts in the 1820s mimicked these rectangular ballrooms



The Leipzig Gewandhaus (Gewandhaus Orchester 1886)

(Beranek 1992, 25). As the 19th century progressed, concert halls grew larger, resulting in halls such as the old Boston Music Hall, completed in 1863, which seated 2400 audience members.

Sabine's Law:

$$RT_{60} = \frac{0.161V}{S\bar{a}}$$

V = Volume of room (m^3)

S = Total surface area of room (m^2)

Sa =T otal absorption (sabins)

Acoustics

In 1898, Wallace Clement Sabine developed an equation to calculate reverberation time from a room's volume, surface areas, the absorptivity of these surfaces, and a constant. Known as Sabine's Law, this equation kickstarted modern architectural acoustics. Previously, architects had emulated the designs of existing successful halls when attempting to design concert halls with good acoustics. In the late nineteenth century, the Gewandhaus in Leipzig was generally considered as the ideal concert hall, and its design was emulated in subsequent halls, to varying degrees of success (Beranek 1992, 27). The Boston Symphony Hall, which Sabine helped design, is one such successful hall which emulates the Gewandhaus.

In addition to reverberation time, acousticians today are aware of more acoustic attributes that are desirable in concert halls. Beranek lists six principal acoustic attributes of concert halls:

- The reverberation time of the room (28);
- Intimacy, or initial-time-delay gap between the sound being made and the audience hearing it (30);
- Loudness of musical sound (31);
- Diffuseness of sound waves (31);
- Lateral reflections to increase the audience's sense of envelopment (32);
- And the early-to-late energy ratio, which compares the strength of early sound to late sound (32).

There is a wide variety of opinions on optimal acoustic conditions for concert halls, especially on what the optimal reverberation time is. In 1941, F.R. Watson wrote that the ideal listening conditions of a concert hall should "comparable with outdoor conditions … that is, with very little reverberation" (Watson, quoted in Beranek 1992, 28). Beranek recommends the following reverberation times for concert halls relative to the era of music intended for performance (29):

- Baroque: 1.6 seconds;
- Classical: 1.8 seconds;
- Romantic: 2 seconds.

Ian Appleton writes that "compositions were written within an acoustic at the time and can have a range of reverberation times of 1.5 to 2.2 seconds" (Appleton 2008, 115). By favouring reverberation times in between these

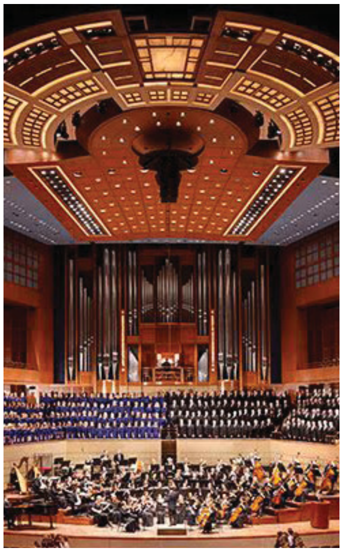
St. Thomas, Leipzig, Germany, looking towards the back (Zarafa 2006)

times, concert halls favour a specific quality of sound, at the expense of others.

Criticism

The churches that saw great choral music had much longer reverberation times than those proposed by acousticians and architects for concert halls. San Marco has a reverberation time of 4.4 seconds (Howard and Moretti 2009, 244), and King’s College Chapel, Cambridge, has a reverberation time of 5.4 seconds (Mo and Horner 2017, 438). J.S. Bach wrote much of his liturgical music for performance in St. Thomas’s Church, Leipzig, which Braxton Boren calculated to have had an average reverberation time of 2.3 seconds when full and 3.1 seconds when empty in Bach’s day (2021, 9). This is much longer than Beranek’s recommendation of 1.6 seconds for Baroque music, though Bach’s music is indubitably standard Baroque repertoire. There is consequently a disconnect between the reverberation times that liturgical choral music was written for and the spaces our society affords for their performance, which have much shorter times.

As I have shown earlier in this chapter, choral church music has adapted to being performed in reverberant spaces. It is designed by composers to maintain clarity and pitch while sounding beautiful in such spaces. To perform such music in a room with a lower reverberation time is to remove an aspect of this music’s character. Architects often emphasize the importance of context to a building, and it is a central tenet of conservation architecture that a building should not be removed from its context. Similar logic can be applied to music: removing music meant to be performed in a



I.M. Pei and Russell Johnson's Artec Consultants, Eugene McDermott Concert Hall, Dallas, United States, 1989 (Collective Cloud 2015)

reverberant setting from such a setting is like moving a train station away from a rail line.

Some concert halls do anticipate the need for higher reverberation times than are usually accommodated for. The Eugene McDermott Concert Hall in Dallas, Texas, employs operable chambers to increase the hall's reverberation time from 1.3 to 3.5 seconds. Such concert halls are excellent for accommodating a wider variety of musical types.

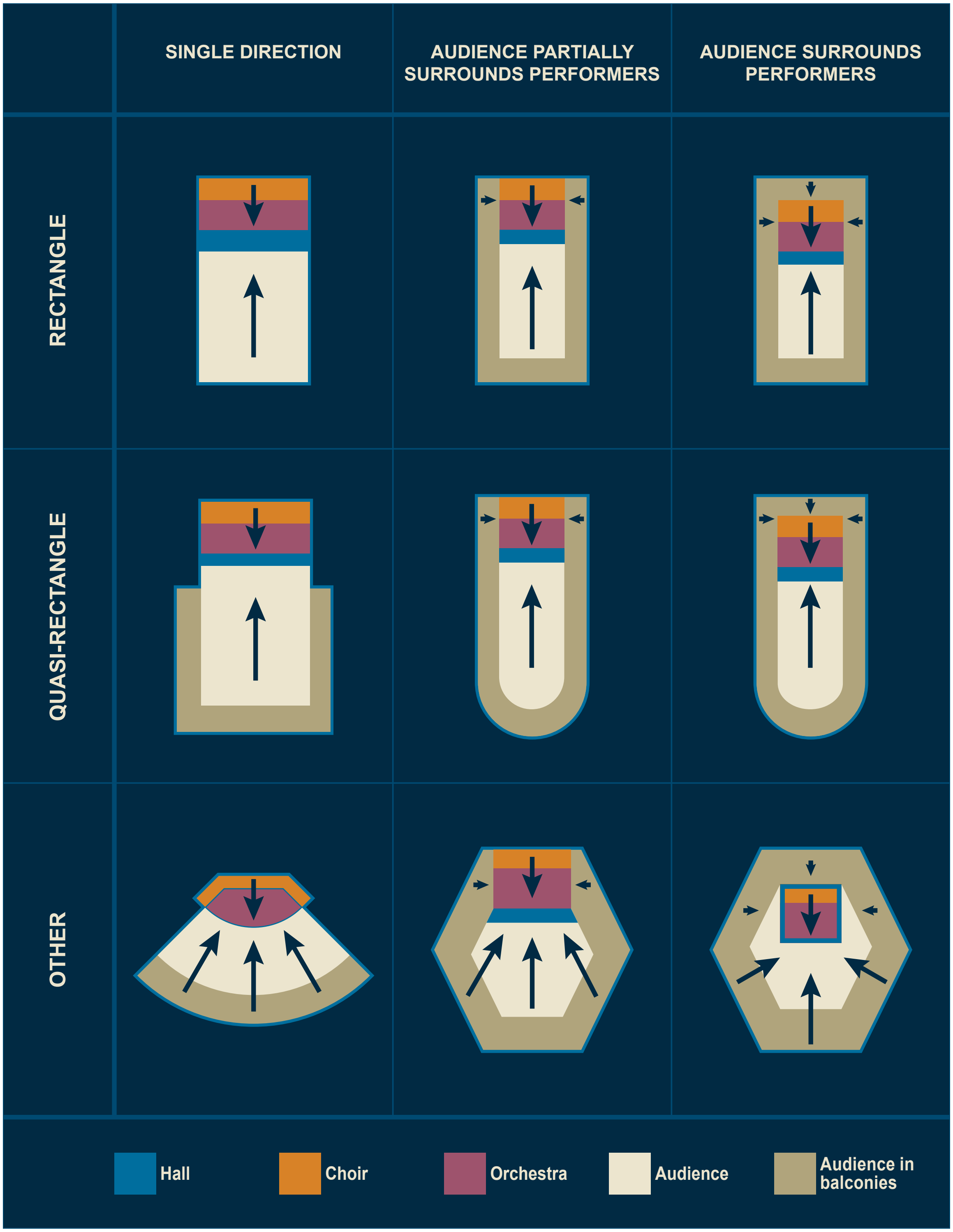
Layouts

There are two main typological threads in early concert hall development: the shoebox and circular theatre types.

Shoebox style halls are rectangular halls that are twice as long as they are wide and tall (1:1:2). These types of halls were extremely popular among early concert halls, reflecting the evolution of concert halls from ballrooms. Their popularity was continued by the acoustic design strategy of copying the designs of extant successful halls: Leipzig's Gewandhaus and Vienna's Grosser Musikvereinsaal are two successful concert halls with shoebox plans (Beranek 1992, 25-27).

Early modern theatres emulated their Greek and Roman predecessors with semicircular plans, following what D'Orazio and Nannini call "circulation" theory (2019, 252). These semicircular plans were hybridized with shoebox plans to produce horseshoe shaped plans, which were the standard shape for 19th century theatres.

Unhappy with being constrained to shoebox plans, 20th century architects developed new concert hall typologies. One such typology is the vineyard type concert hall, popularised by the Berlin Philharmonie. Beranek writes



Typology of concert hall plans, categorizing concert halls relative to the relationship between performers and audience (adapted from Appleton 2008) that the acoustic success of these halls is due to the low retaining walls supporting each terraced balcony, which provide “lateral reflections to the listeners and short initial-time-delay gaps” (1992, 38).

Despite the differences between these typologies, they all share one feature in common: there is one, central stage, at which the whole audience looks. The remainder of the room is engineered to optimize the distribution of sound from the stage outwards, while inhibiting the passage of audience noise back at the stage. This strategy is effective for creating good listening conditions for audiences, but precludes polychoral music being performed with the choir distributed spatially in a concert hall.

Criticism

Performances of polychoral music where the choirs are distributed spatially result in dynamic and exciting performances that are enjoyed by audiences. Being sat in between choirs, for example, enables audiences to perceive how the music bounces back and forth in double choir and polychoral music. Recently in Halifax, the choir of All Saints Cathedral performed a concert that was choreographed to move portions of the choir around the cathedral and incorporated some polychoral music, including Jacob Handl’s *Pater Noster* and Gregorio Allegri’s *Miserere Mei*, Deus. Audiences enjoyed how the choir moved around. One audience member complemented the performance, writing that:

> [The choir] made maximum use of the full acoustic possibilities of the Cathedral. It was wonderful to hear the widely spread antiphonal sound from the tran[s]epts in the Handl ‘Pater Noster’ and then to have the choir behind us with the solo quartet at the High Altar for the Allegri. (Paul Halley, personal communication, June 3, 2023).

All Saints Cathedral, Halifax

Other audience members complemented the "beautiful choreography" and commented that they were "immersed in sound," while others found the exploration of the cathedral's acoustics "inspiring" (Paul Halley, personal communication, June 3, 2023). By being designed for sound to move only from the stage outward, concert halls limit performance opportunities by inhibiting more dynamic uses of architectural space.

In addition to adding interest and excitement to performances, the spatial distribution of choirs results in certain voices being heard more strongly than others. While an equal blend of voices is usually desired, this is readily available in recordings, which can be accessed easily through the internet. By contrast, only live performances offer audiences the experience of an unequal blend of voice and of singers moving around. Additionally, an unequal blend of voices enables different aspects of a piece to be heard. This is exemplified in Janet Cardiff's sound sculpture, *40 Part Motet*, which is a specialized recording of Thomas Tallis's forty voice composition, *Spem in alium*. To build her sound sculpture, Cardiff recorded each of the forty parts on a separate microphone, and then plays each recording on its own speaker. The audience can then move between the forty speakers. In recordings and when performed with the choir all grouped together, only the upper soprano parts can be easily distinguished from the morass of sound, and it is quite difficult to hear the inner and lower parts. By being able to essentially move around the choir as they

Installation of Janet Cardiff's 40 Part Motet in the National Gallery of Canada sing, Cardiff's sound sculpture enables audiences to hear all the inner parts of the composition. Here, an unequal blend of voices benefits the listener and enables them to better comprehend the whole composition. *Spem in alium* consists of eight choirs of five voices each, an organization that Cardiff retains in her sculpture. As such, the sculpture therefore also allows audiences to experience how the choirs respond across the space to each other. Housed in the National Gallery of Canada, Cardiff's sculpture is widely enjoyed, even by those otherwise unfamiliar with choral music, demonstrating the enjoyment audiences receive from dynamic uses of space in performances.

Summary

Housed in churches, rather than concert halls, for centuries, choral church music has adapted to a wide variety of church acoustics and plan types. As the acoustic design of churches was limited prior to the development of modern architectural acoustics, few churches were designed to suit the needs of choral music, though the designs of Jacopo Sansovino and William Critchlow Harris prove the exception to this. Consequently, composers had to adapt their compositions and performances to the acoustic spaces they were dealt, often designing their music so as it inhibit reverberation from negatively impacting the clarity and tuning of their works. However, the layouts of churches also provided composers with ways to add dynamism to their works through the use of architectural space in polychoral compositions.

This rich connection between choral music and architectural space is interrupted by concert halls. Designed primarily for orchestral music, concert halls have low reverberation times and are designed for sound to only travel outwards from the stage. Singing music meant for two or more choirs from a single stage, or music written for a long reverberation time in a room with a short one, causes that music to lose some of its character.

In Europe, this can easily be remedied by staging productions of such music in churches and cathedrals with the appropriate acoustic conditions. However, Canada does not possess as many large, reverberant churches. Additionally, as church congregations dwindle and more and more churches are decommissioned and demolished, Canada’s stock of reverberant churches is being lost. Adaptive reuse of churches into concert halls helps to retain this stock. It also mixes together the typologies of churches and concert halls, providing designers the opportunity to benefit from the advantages that both churches and concert halls afford.

Chapter 4: Design Methodology

Lydon Lynch and Thomas Payne Architects, Joseph Strug Concert Hall, Dalhousie University, Halifax, Canada, 2023

As I have shown in the previous chapter, choral church music utilizes acoustic space in ways that normative concert halls do not allow. Concert halls, being designed to have sound propagate from the stage, do not encourage performances where the choir surrounds the audience, as in polychoral music. Additionally, as they are designed specifically to have suitable reverberation times for orchestral music, the acoustics of concert halls are much different from those of churches, few of which have been designed acoustically. While this does benefit some forms of music, it impedes others, such as Gregorian chant, from being properly appreciated.

Concert halls can be better adapted to choral music through two methods: by designing for a flexibility of reverberation times (including accommodating higher reverberation times than those typically encouraged), and by designing to accommodate a flexibility of sound source configurations. It is possible to manipulate reverberation times and the propagation of sound by altering three variables: the form of a room, its materials, and the configuration of sound sources relative to listeners.

In the following chapter, I will outline and challenge the optimal acoustic requirements for concert halls, my goals in relation to these requirements, and my methodology for meeting these goals.

Optimizing Reverberation Time

Reverberation Time

Acousticians recommend optimal reverberation times for rooms relative to their intended use. Rooms to be used for speech should have low reverberation times, while rooms intended for music are permitted higher times depending on the type of music in question. David Egan recommends the following ranges in reverberation time (1988, 64):

- Rooms for speech: 0.4 to 1.2 seconds;
- Rooms for orchestral music: 1.7 to 2.3 seconds;
- Rooms for liturgical music: 2.0 to 2.6 seconds.

These recommendations are fairly similar to those Leo Beranek and Ian Appleton make, listed in Chapter 3, with Egan permitting higher reverberation times than Beranek and Appleton.

It must be noted that these recommendations are made by Western scholars with Western music in mind. Given that the recommendations for optimal reverberation times made by Egan, Beranek, and Appleton are disputable even within Western music, their recommendations cannot be assumed to be suitable for the music of non-Western cultures. I had the opportunity to observe this in Halifax at a performance of Persian music in a church I sing at, St. David's Presbyterian. While the St. David's choir does not consider the church to be reverberant (we consider it a good day's work when we can get the church's acoustics to ring at all), the Persian musicians brought carpets with them to absorb sound, they considered the church to be so reverberant. This significant difference in opinions about the acoustics of the same space demonstrates how culturally conditioned our response to acoustics can be.

Persian carpets laid in the chancel of St. David’s Presbyterian Church, Halifax, Canada. David Stirling, 1869

Additionally, the opinion of audiences and acousticians on suitable reverberation time differs form that of performers, with performers enjoying longer reverberation times. Howard and Moretti suggest that singers tend to prefer reverberant spaces, writing that the dry conditions of the smaller Venetian churches they surveyed were “not welcomed by the singers [in their study], who found [the] spaces unresponsive” (2009, 159). I also prefer to sing in reverberant spaces, as do the majority of my fellow singers in church choirs in Halifax. I suggest two reasons why performers may have such a preference.

Firstly, and most importantly, performers benefit from hearing a room’s response to their sound, as it helps them feel supported and to gauge their dynamics. Singing in a space where the sound does not return is unnerving and difficult for a singer to judge their own dynamic in, while singing in a space that soaks up all sound is difficult and discouraging. By contrast, singing in a reverberant space feels much easier, as less sound is needed to fill such spaces. Also, reverberant spaces are more forgiving to performers, as the reverberation can cover small breaths and mistakes, while a dry acoustic leaves them very evident.

Secondly, performers experience a more appropriate ratio of early-to-late sound than audience members do. A ratio balanced too strongly towards late sound can cause a decrease in clarity as the late sound interferes with the early sound. Meanwhile, early sound can remain clear with a high early-to-late ratio, and with a pleasant tail of reverberation. As the sound sources, performers experience a higher intensity of early sound than audiences. Consequently, though the late sound may be consistent for both audience and performers, the ratio differs, with performers experiencing a more appropriate ratio balanced towards initial sound.

Bass Ratio

Reverberation time also differs relative to pitch. Generally, low frequencies have longer reverberation times than high frequencies (Beranek 1992, 27). Bass ratio is a measurement used to compare the lengths of reverberation times in a room relative to frequency. Egan recommends for music performance halls that the ratio of reverberation time of low frequency sound (the average of 125 Hz and 250 Hz) to mid-frequency sound (the average of 500 to 1000 Hz) be 1.2 (1988, 155). He equates a high bass ratio with a sense of “warmth” (155), while warning that too low a bass ratio may result in a hall sounding “shrill” (125).

Goals and Methodology

For the design of the concert hall in the United Memorial Church, I aimed for a reverberation time of 2 seconds when half full. This number sits comfortably in the middle of the reverberation times that Egan recommends, and at the upper end of the recommendations made by Appleton and Beranek. However, I incorporated elements of the design to increase and decrease the room's reverberation time to the benefit of the performance taking place. These elements include operable curtains to decrease the reverberation time, and additional volume to increase it, like in the Eugene McDermott Concert Hall.

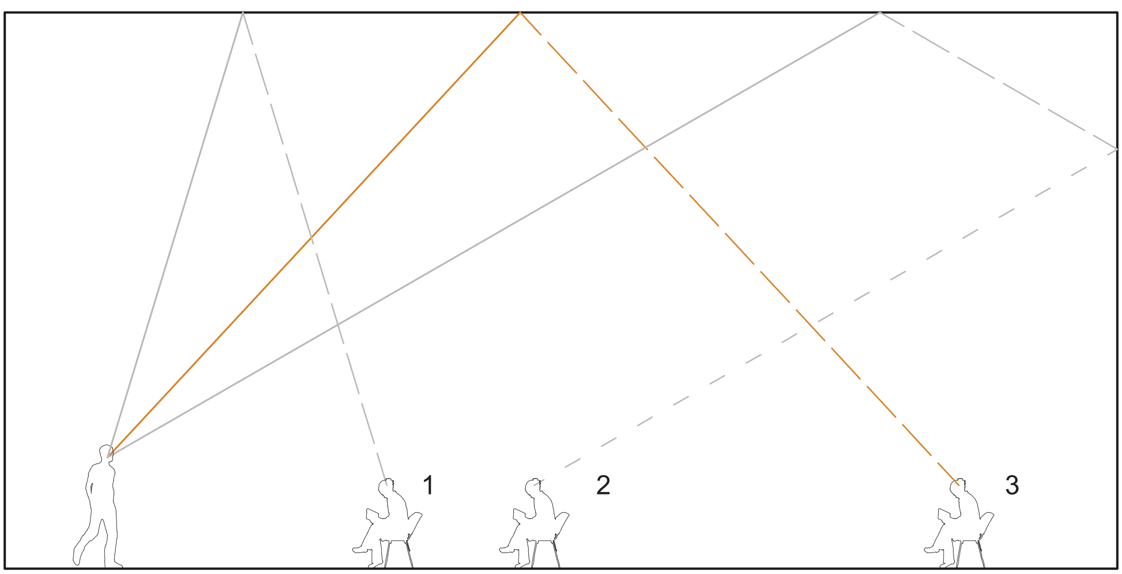
For bass ratio, I aimed to achieve Egan's recommended ratio of 1.2.

To estimate both reverberation time and bass ratio, I used Sabine's Law . This involved tallying the surface area of all surfaces within a room; recording these areas, their material, and their absorption coefficients; and calculating the room's volume.

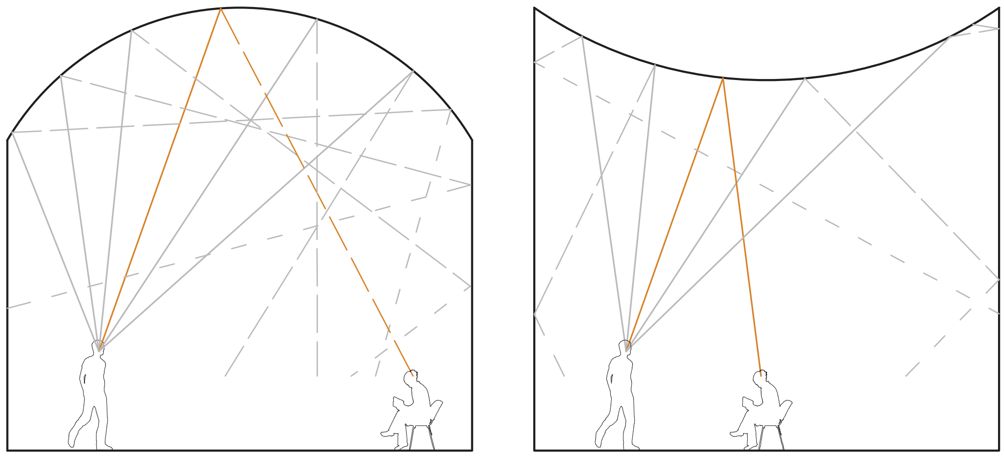
Optimizing Room Shape

Concert halls are designed so that the room's shape and materials optimize the propagation of sound from the stage to all other parts of the room. Part of this includes designing concert halls so that disruptive sound does not return to the stage, where it might distract the performers. While this is certainly effective, it also limits performance potentials by restricting sound to only coming from the stage.

In order for concert halls to optimize the propagation of sound from the stage to the whole audience, designers control the way sound reflects off surfaces and diffuses around a room. Mapping the propagation of sound using ray diagrams is an effective way to optimize a room's shape. Sound reflects off a surface when the surface's dimensions are twice to four times as large as the wavelength being reflected (Egan 1988, 89). When sound reflects, it reflects similarly to how light does, with the angle of incidence equal to the angle of reflection. Drawing sound as rays allows designers to visualize how sound will travel through a room, and measure the path length of the sound. Discrete echoes can be heard when the reflected sound is heard more than 0.06 seconds after the initial sound, or when the path length of the reflected sound exceeds the path length of the direct sound by 20.7 metres (Egan 1988, 96). Ray diagrams can therefore be used to measure the path difference. Egan recommends that path differences be less than 7 metres (20



Example ray diagram



Effect of concave vs. convex surfaces on sound propagation

milliseconds) for excellent listening conditions, and that path differences up to 10 metres are “fair” listening conditions for music.

It is also important that performers receive early reflections of their own sound in order to feel supported by a space. Singing in places where the sound does not return can leave singers feeling exposed and unsupported, while singing in places where it does return bolsters singers’ confidence. Sound must also be able to travel from one side of the choir to the other side effectively, be this choir spaced out across of room or grouped together, to ensure that the members of a choir can remain in time with each other.

Egan stresses the importance of diffusion in rooms for music, writing that “when satisfactory diffusion has been achieved, listeners will have the sensation of sound coming from all directions at equal levels” (89). Diffusion occurs when sound waves are scattered after encountering a surface with depths comparable to that of the wavelength (89). Convex surfaces are excellent for diffusing sound, while concave surfaces are unadvisable acoustically, as they can focus sound.

Goal and Methodology

I designed this concert hall to have multiple spots suitable for choirs to perform from. This included enabling the choir to sing from the back and side balconies, and flattening the main level's floor so that chairs can be moved around to suit the performers' preference.

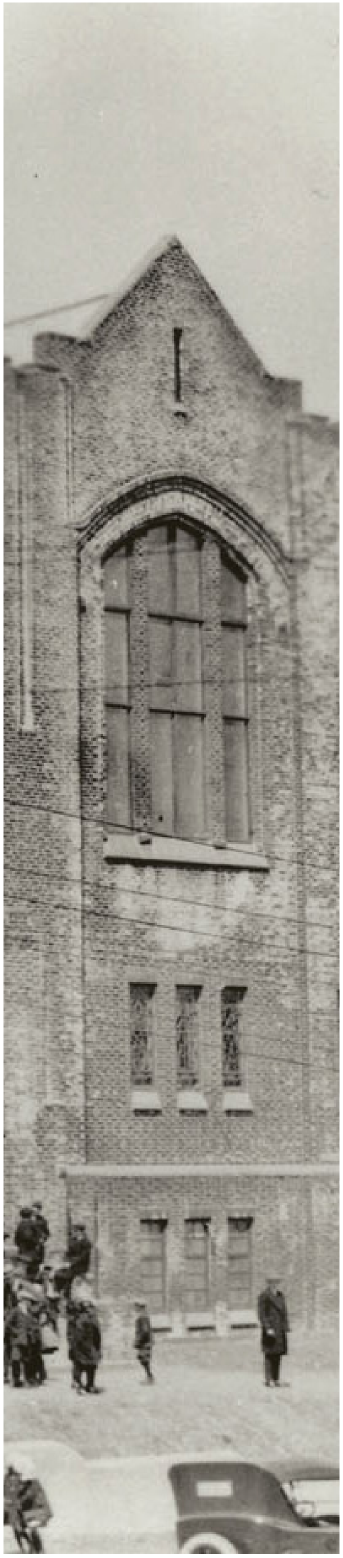
Using ray diagrams, I optimized the propagation of sound from these multiple singing locations so that the path differences are ideally less than 7 metres, though I have deemed 10 metres acceptable, following Egan's advice. I paid especial attention to how the sound travels around the stage in both plan and section to ensure that singers are adequately supported by the room, as well as to how effectively sound travels between parts of a divided choir.

Ceilings, cornices, acoustic baffles, and walls have all been manipulated to control where sound bounces and to shorten the path of reflected sound.

Summary

Concert halls can be adapted to the needs of choral music by designing them to accommodate a wider range of reverberation times and sound source configurations. These modifications, while benefitting choral music, also serve concert halls by making performances more dynamic and exciting. In Halifax, the All Saints Cathedral choir recently completed a concert where they moved the choir around the church to give contrast between vocal parts or to use different aspects of the cathedral's acoustics. The cathedral is not designed acoustically, so some of the choral positions were less than ideal, but this tactic nonetheless added dynamism and excitement to the concert, which was well received by the audience. In a room where these multiple positions were well designed, such a performance would be even more effective and exciting. Designing a concert hall to have the flexibility and long reverberation of churches, alongside the optimizing acoustics of concert halls, seems an ideal way to do choral music justice within contemporary and secular spaces. Such an approach is suited not only to the United Memorial Church in Halifax, but to any other church or concert hall that aims to be well used by choirs.

Chapter 5: The United Memorial Church



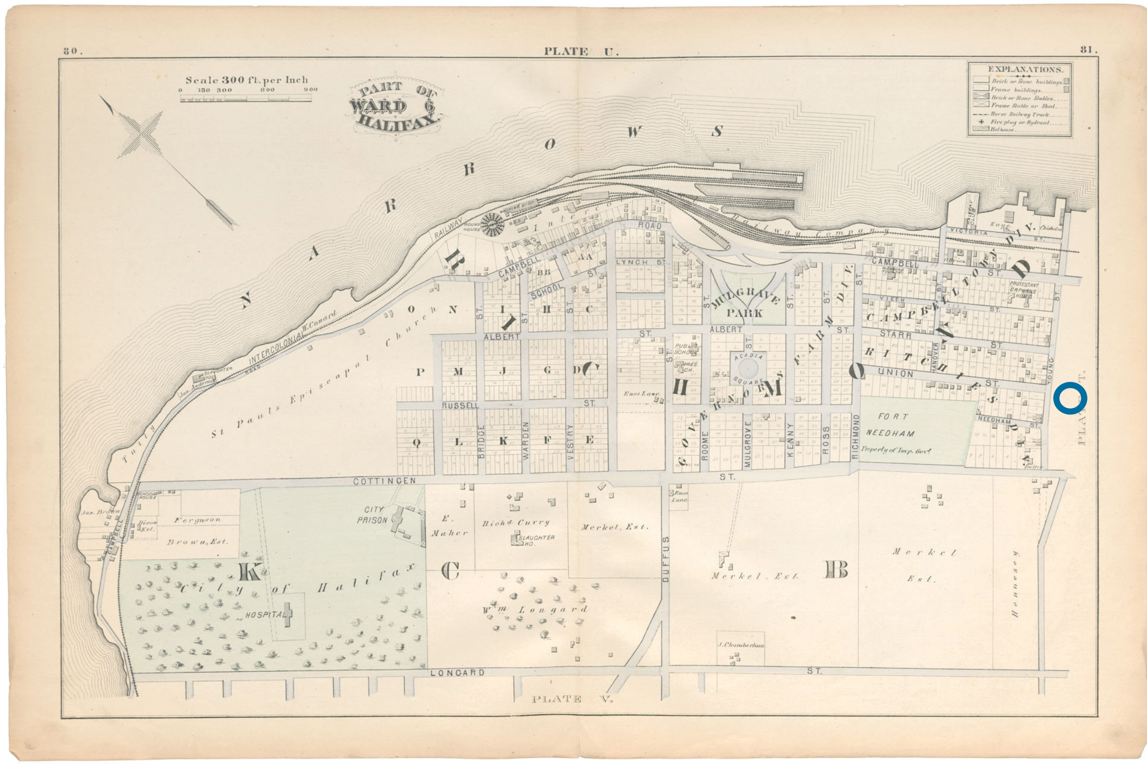
Andrew Cobb, United Memorial Church, Halifax, Canada, 1921 (Cox Brothers 1921)

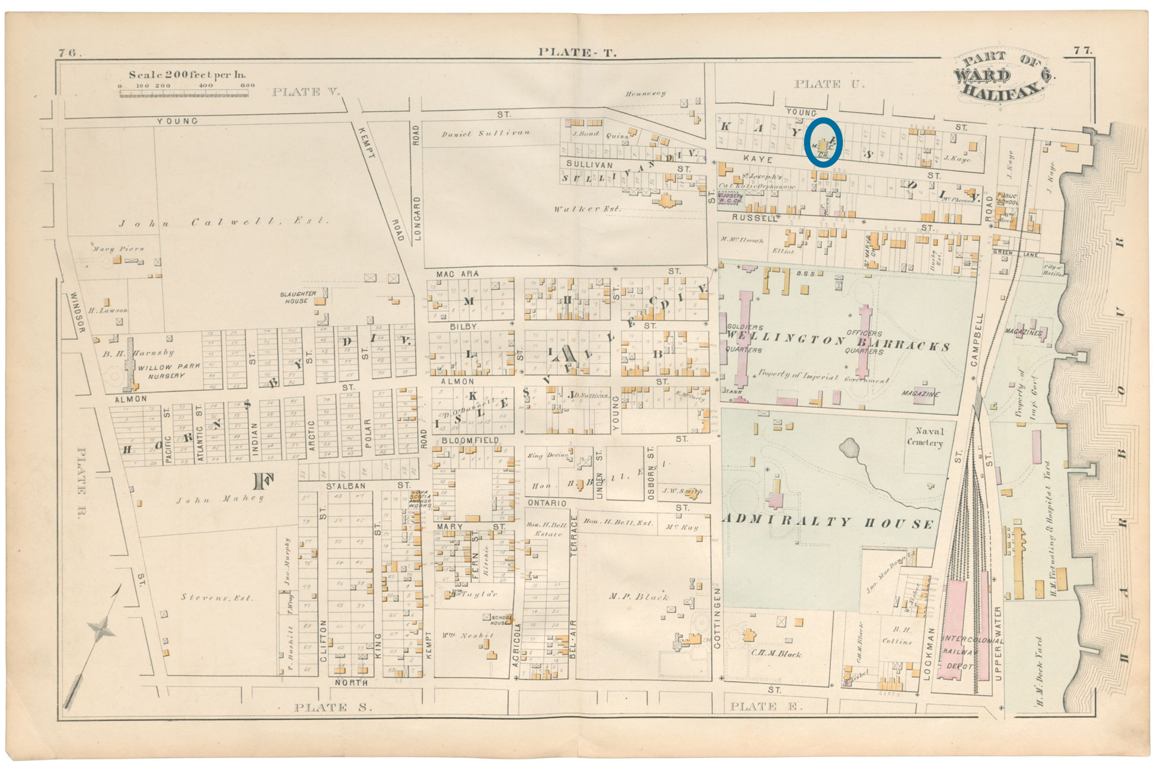
This thesis will be tested on the United Memorial Church, situated in Halifax, Nova Scotia. Despite having significant heritage value, the church was set to be demolished by developers after being decommissioned in 2015, but has since been bought by a new set of developers who intend to retain the historic structure through adaptive reuse. The church's heritage value in relation to the Halifax Explosion, the United Church of Canada, and to architect Andrew Cobb, as well as its advantageous positioning on the Halifax peninsula, make it an ideal site to test this thesis of retrofitting churches into concert halls. Additionally, the church's existing architecture lends itself well to becoming a concert hall.

Heritage Significance

Halifax Explosion

The United Memorial Church is situated on the slopes of the harbour side of Fort Needham Hill in Halifax's North End. This hill is similar in elevation to Citadel Hill, and was likewise used historically for the military defence of Halifax. Halifax was first occupied by the British in 1749, having appropriated the land from the Mi'kmaq people. For the first century of Halifax's history as a British colonial city, the North End was largely rural and used for military endeavours, though this began to change in the 1850s. This decade saw construction begin on new military barracks, then known as the Wellington Barracks (Erickson 1984, 23), now known as C.F.B Stadacona. In 1854, Halifax's first train station was built near North Street, and Fort Needham





Location of the United Memorial Church circled in blue on plates U and T of H.W. Hopkins' City Atlas of Halifax (Hopkins 1878)

Hill partitioned by the Province to be sold as subdivisions. These subdivisions developed into the area of Richmond, containing Mulgrave Park and Acadia Square. By the 1870s, important businesses in Richmond included Imperial Oil, Richmond Printing, Gunn Feed Mill, Hillis and Sons Foundry, the Halifax Graving Dock, and the Acadia Sugar Refinery (25). In 1878, the new North Street Station was opened by Intercolonial Railway, which was at the time the second largest train station in Canada.

By 1917, Richmond was densely populated, based around industries, transportation routes, and military institutions situated along the waterfront. Half the population of Halifax lived in Richmond (Davidson Elliot 2019). Topographically, the area spanned the slope of Fort Needham, from the crown of the hill down to the water. This siting and density made Richmond extremely susceptible to damage from the Halifax Explosion.

The Halifax Explosion occurred as a result of two ships colliding as they passed through the Narrows, the narrow passage between Halifax and Dartmouth that links Bedford Basin with the Halifax Harbour. One of the ships, the SS *Mont Blanc*, had a cargo of explosives, on its way to the battlefronts of World War I. The collision caused a fire on the *Mont Blanc*. The ship drifted to Pier 6 on the Halifax shore before the fire ignited the ship's cargo, causing the *Mont Blanc* to explode at 9:05 am. With no topography to shield it from the blast, Richmond saw the brunt of explosion, which was powerful enough to be felt over two hundred kilometres away in Cape Breton and send the Mont Blanc's anchor flying three kilometres. What buildings in Richmond that were not immediately levelled by the explosion were later destroyed by fires. 1782 people are confirmed to have been

Damage to St. Joseph's Convent, which stood on the corner of Kaye and Gottingen Streets (Gauvin and Gentzel 1918)

Devastation on Kaye Street near Gottingen Street. The Church site is likely just after the large houses still standing (MacLaughlan 1917 or 1918)

Devastation caused by the Halifax Explosion. Looking uphill from the railway tracks, this panoramic photo may contain the United Memorial Church's location. (MacLaughlan, 1917)

killed by the Explosion, and thousands more injured. Many of these people were blinded by flying glass, including some who would become parishioners of the United Memorial Church.

As the Explosion left thousands of Haligonians homeless, reconstruction of the devasted area began quickly. This redevelopment was led by the Halifax Relief Commission (HRC), a federally and provincially incorporated commission tasked with expending and dispersing funds "to repair, rebuild and restore buildings and property damaged, destroyed or otherwise lost as a result of the Halifax Explosion" (NS Archives, "Halifax Relief Commission"). While the architectural firm Ross and Macdonald did complete "the lion's share of construction in the metropolitan area" following the Explosion, local architects contributed to the rebuilding of Halifax's North End as well (NS Archives, "A Vision of Regeneration"). Among these Nova Scotian architects is Andrew Cobb, architect of the United Memorial Church.

The Explosion destroyed multiple churches in the Richmond area, including the Grove Presbyterian and Kaye Street Methodist churches. 239 parishioners from the two churches were killed (Kitz 1985). After sharing a temporary church immediately following the Explosion, these two congregations decided to amalgamate and construct a single replacement church, the United Memorial Church. The church was dedicated to the memory of the victims of the Explosion. For over fifty years, it also housed a set of carillon bells donated by Barbara Orr in memory of her family, who died in the Explosion. These bells have since been removed from the tower (which was deemed structurally unsound) and relocated to the Memorial Bell Tower in Fort Needham Memorial Park (Kitz, 1985).

Kaye Street Methodist Church. (Halifax Municipal Archives CR58.28.7)

Grove Presbyterian Church. (Halifax Municipal Archives CR58.28.5)

The UMC is richly tied to the Halifax Explosion, having been built in response to the Explosion on land only 700 metres from the epicentre, and to memorials for the Explosion, having housed the carillon now situated atop Fort Needham Hill. Such a historically significant church is crucial to maintain in order to continue collective memory of the Halifax Explosion.

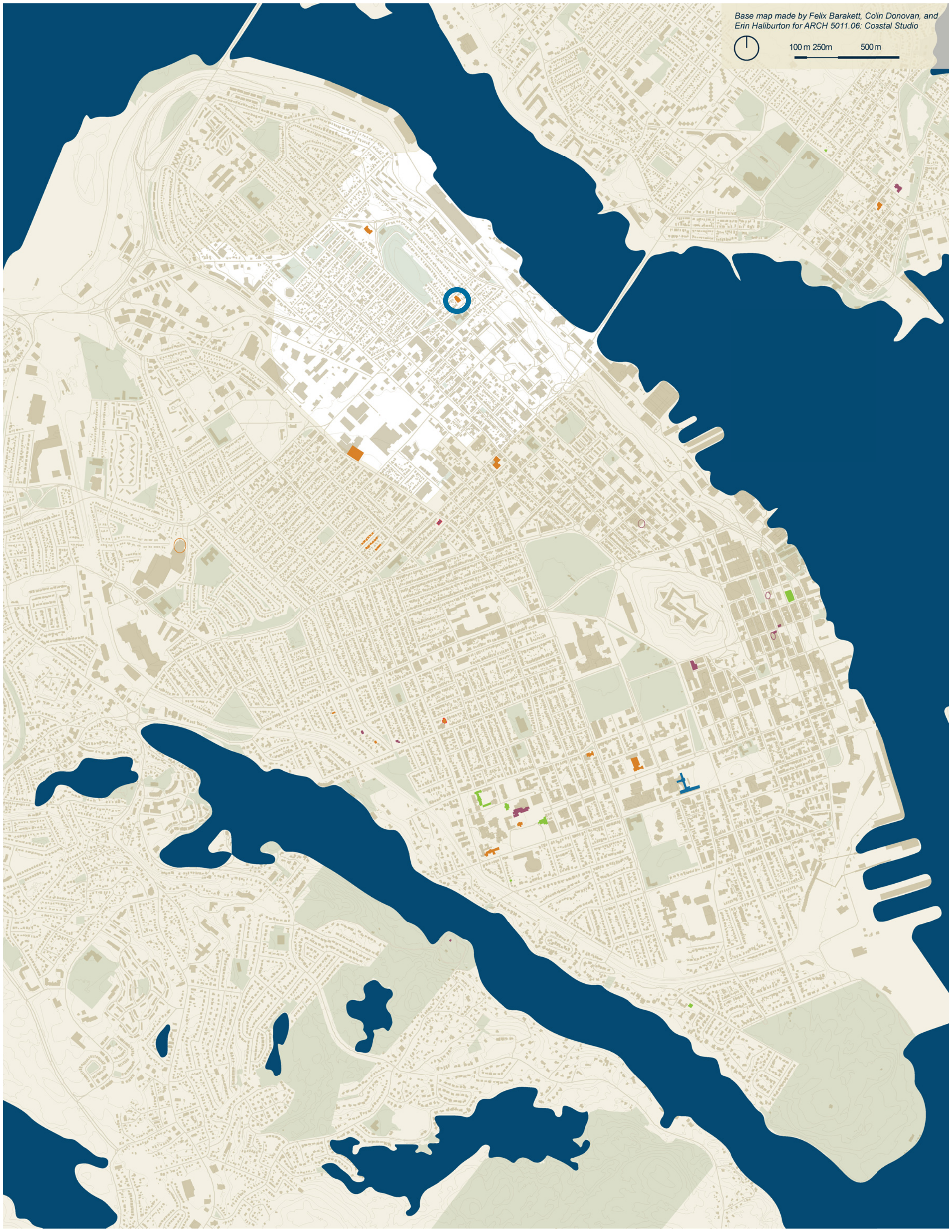
United Church

As the amalgamation of the Grove Presbyterian Church and Kaye Street Methodist Church, the United Memorial Church is the first United church in Canada. The two congregations had shared a temporary church since 1918, got along well together, and decided to unite into a single congregation when their new church was constructed. As such, this United church "preceded the establishment of the United Church of Canada by approximately four years" (McGreal 2022, 4), adding to the church's national significance.

Architectural Significance

The United Memorial Church is architecturally significant as one of the works of Andrew Cobb. Schooled at Acadia University, MIT, and the École de Beaux-Arts in Paris, Cobb was a respected and established architect in Halifax when the Explosion occurred. In the four years following the Explosion, Cobb completed the designs of:

- Richmond High School, Devonshire Avenue (1919);
- St. Andrew's Presbyterian Church, Coburg Road (1919);
- St. Patrick's Roman Catholic Boy's School, Brunswick Street (1919);
- St. Thomas Aquinas Catholic Church Parish Hall, Oxford Street (1919);
- Jewish Synagogue, Robie Street (1920);



Map of Andrew Cobb's buildings in Halifax, with United Memorial Church circled in blue (basemap from ArcGIS, 2021)

Demolished

Area devastated by Explosion

Constructed in:

≤1917

1918-1927

1928-1937

1938≤

Andrew Cobb, Richmond School, Halifax, Canada, 1921 (Gauvin and Gentzel 1921)

- United Memorial Church, Kaye Street (1921);
- Ardmore Housing Development, Seaforth and Summit Streets (1921).

Of these, only the Richmond School and United Memorial Church are recognized as work to regenerate Halifax following the Explosion, likely because only these two exist within the confines of the historical Richmond. However, the Ardmore Housing Development, which includes 32 housing units, almost certainly was also designed in reaction to the need for housing following the Explosion.

Though designed early in Cobb's career as an architect, the United Memorial Church was the fifth of the seven churches he designed. The full list of churches he designed is:

- St. Andrew's Presbyterian, Wolfville (1914) - *now Church Co. Brewery;*
- Central Methodist, Moncton (1916) - *now United:*
- St. John's Presbyterian, Halifax (1917) - *turned United, then demolished in 2016;*
- St. Andrew's Presbyterian, Halifax (1919) - *now United;*
- United Memorial (1921);
- First Baptist, Dartmouth (1922);
- University of King's College Chapel (1928).

Demolished

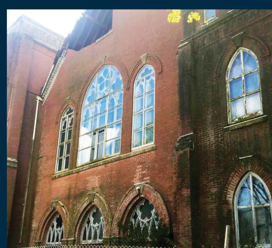
St. John's United, Halifax (1917)

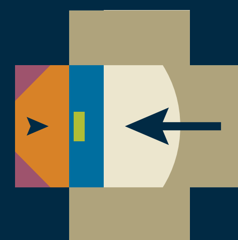
Decommissioned

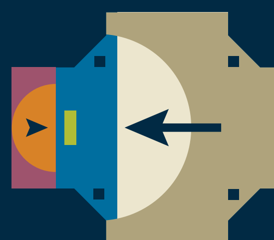
St. Andrew's Presbyterian, Wolfville (1914)
United Memorial, Halifax (1921)
First Baptist, Dartmouth (1922)

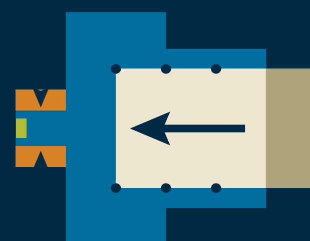
Still active churches

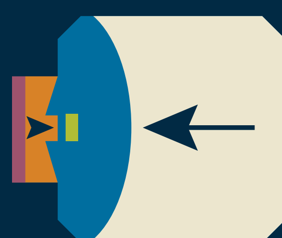
Central United, Moncton (1916)
St. Andrew's United, Halifax (1919)
University of King's College Chapel, Halifax (1922)











Andrew Cobb's seven churches

Of these seven, only three are still active churches. St. John's was demolished in 2016, and St. Andrew's (Wolfville), United Memorial, and First Baptist have all been decommissioned. Of the three remaining, two have strong links to the city's musical community. St. Andrew's (Halifax) hosts many of Symphony Nova Scotia and the Halifax Camerata's concerts, and King's is home to an Oxbridge style chapel choir which sings at least two services a week throughout the school year. Despite the musical legacy of

United Memorial Church in 2022

his churches, Cobb is not known for the acoustic qualities of his spaces – his churches are neutral acoustically, neither excellent nor awful.

Location in Halifax

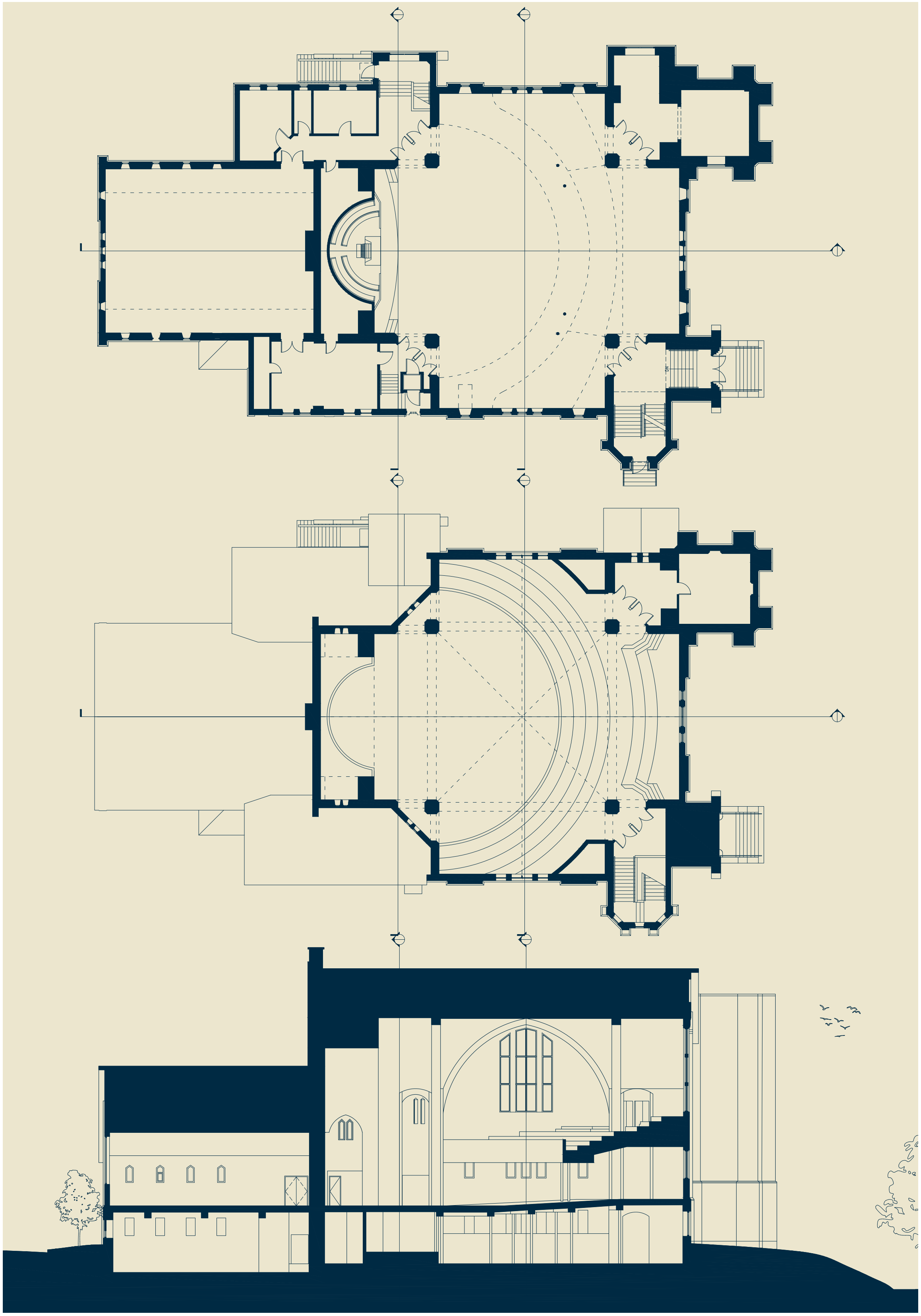
The United Memorial Church is located on the peninsula, between Barrington and Gottingen streets. The 7A, 7B, 29, and 84 bus routes all stop within a 500 m radius of the church. This makes the church quite accessible to the rest of the peninsula, especially to inhabitants without cars. This is an asset to young musicians, many of whom do not have cars. This location is consequently accessible to wide range of Halifax's population of musicians.

Interior of the church in 2014 (Luck 2014)

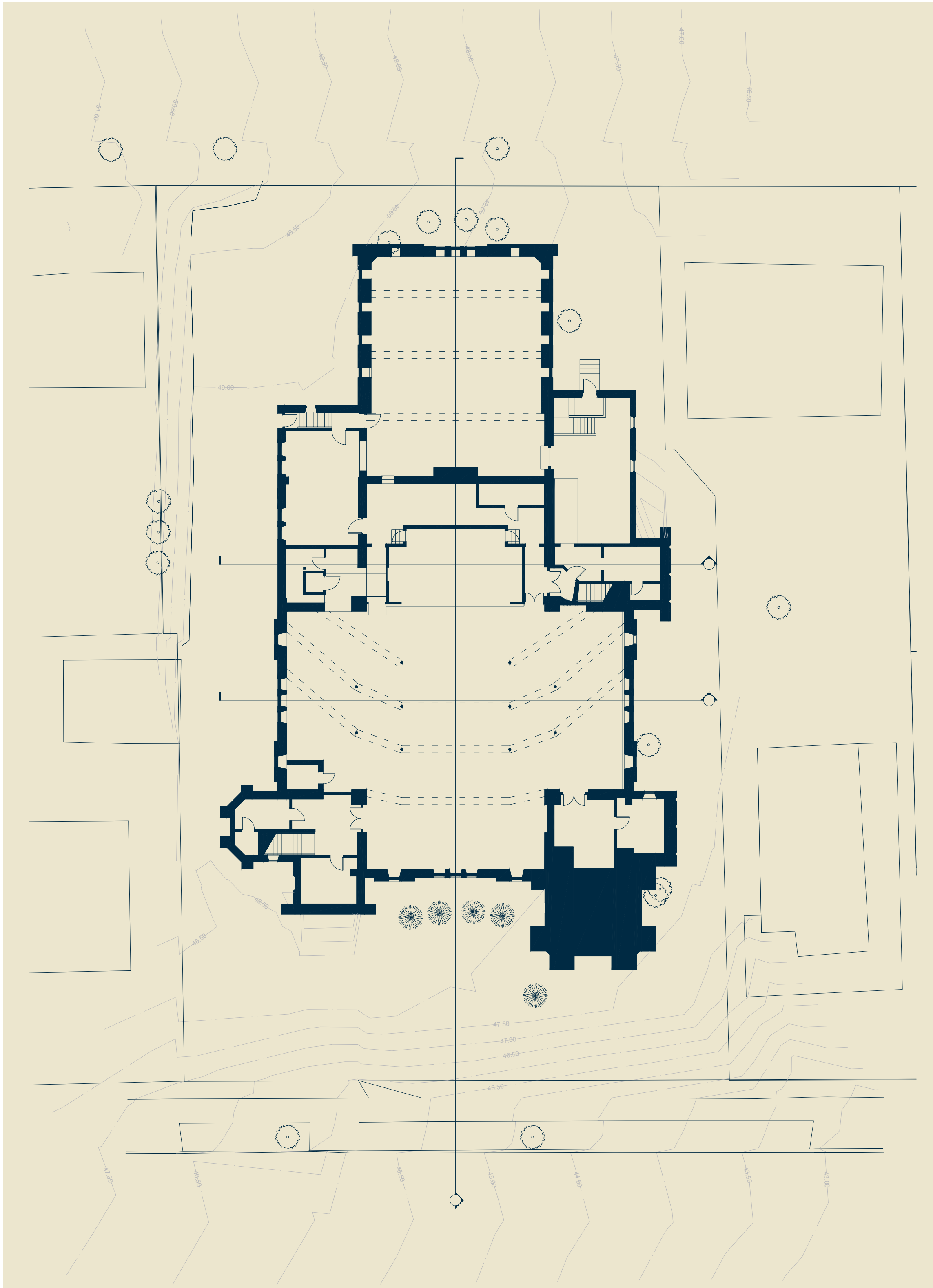
The United Memorial Church's Architecture

On the exterior, the United Memorial Church reflects a local shift towards more modern styles, and was likely influenced by early Art Deco (McGreal 2022, 4). Its brick structure also reflects how the Halifax Explosion gave rise to a "preference at the time for durable construction materials" (McGreal 2022, 4). Numerous changes have been made to the exterior of Cobb's design, however. Cobb's fine brick parapet, slate shingles, and decorative mouldings were scrapped in preference for a more easily maintained asphalt shingle roof structure, with eaves overhanging the walls. The brick walls have been painted over in red, as though to match the tone of the bricks. Most importantly, the top of the bell tower was removed for structural reasons (McGreal 2022, 5).

The interior of the church is a mix between Greek Cross and auditorium type plans. Following the Greek Cross plan, all arms of the church are equally deep (save that which



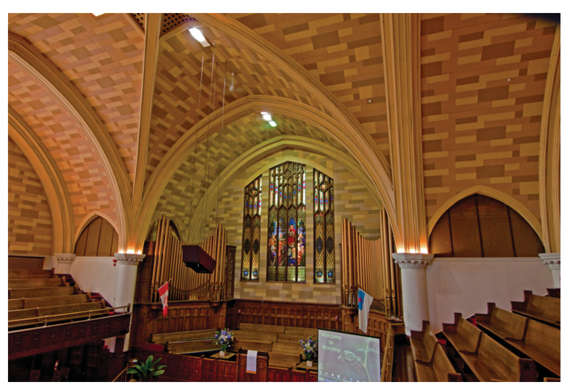
Existing 1st and 2nd floor plans, and longitudinal section
1:400



Existing site plan
1:400

holds the organ and choir). Following the auditorium style plan, the congregation occupies semi-circular pews and a balcony that radiate out around the altar, bringing the congregants as close to the priest and altar as possible. The choir is located at the front of the church behind the altar, also arranged in a semi-circle. The organ is then located behind the choir. This layout is similar to that of a concert hall in that the audience's seating is arranged to focus on a single, centralized point.

The plan, section, and elevations of the United Memorial Church bear a noticeable resemblance to Cobb's design of the Central United Church in Moncton, completed five years earlier in 1916. Though I have found no documentary evidence to prove this, their similarities are such that Cobb likely drew inspiration from the Moncton church when designing the Halifax one. Both employ the mix between Greek Cross and auditorium plans, with the choir facing the congregation behind the altar in one gable end, and balconies occupying the other three ends. The elevations of these gable ends match as well between the Moncton and Halifax churches. Both employ flat gabled roofs but arched ceilings; have large, triptych windows; and have parapets



Front facade and interior of the Central United Church in Moncton (Macdonald 2020; Macdonald 2018) with rectangular massing for decoration. It is possible that Cobb chose to emulate the Moncton church for the design of the United Memorial Church because both churches have Methodist roots. The Moncton church was Methodist prior to the United Church unifying, and the United Memorial Church occupies the site of its Methodist predecessor.

The Moncton and Halifax churches do have numerous differences as well. The Moncton one is firmly Neo-Gothic in decoration, while the Halifax one has much less ornamentation and is considered to be an early example of Art Deco design (McGreal 2022, 5). While the Moncton church has a rectangular balcony, the Halifax one has a semi-circular one, as well as diagonal wall to chamfer the corners between the gable ends, likely to increase visibility. Additionally, the Moncton church has the choir is seated in an octagonal fashion, whereas they are seated in a semi-circle in Halifax.

Acoustic Conditions

The United Memorial Church is remembered by community members as having “lovely acoustics” that choirs enjoyed singing in (Jordan Gracie, personal communication, February 7, 2023). The back balcony is low over the first flow and quite deep, and probably has the effect of trapping sound in between balcony’s soffit and floor. I estimated the existing reverberation time to be 2.36 seconds when empty and 1.90 seconds when full, assuming the composition of various materials from images and videos published online (see Appendix B for calculations).

Summary

The heritage significance of the United Memorial Church is immense as a memorial to the Halifax Explosion. Its position as an Andrew Cobb design and as the first United church in Canada adds to this value. Such a significant structure should be valued and maintained. If the church's congregation was not able to do so, the church is an ideal site for sensitive adaptive reuse that will provide the building with a new use while preserving and honouring its heritage value. The church's interior layout makes it very feasible for being adapted into a concert hall, and the church's location within Halifax supports arts programming for musicians of all ages. As such, the United Memorial Church is an ideal site for testing a thesis on the adaptive reuse of churches into concert halls.

Chapter 6: The Richmond Memorial Arts Centre

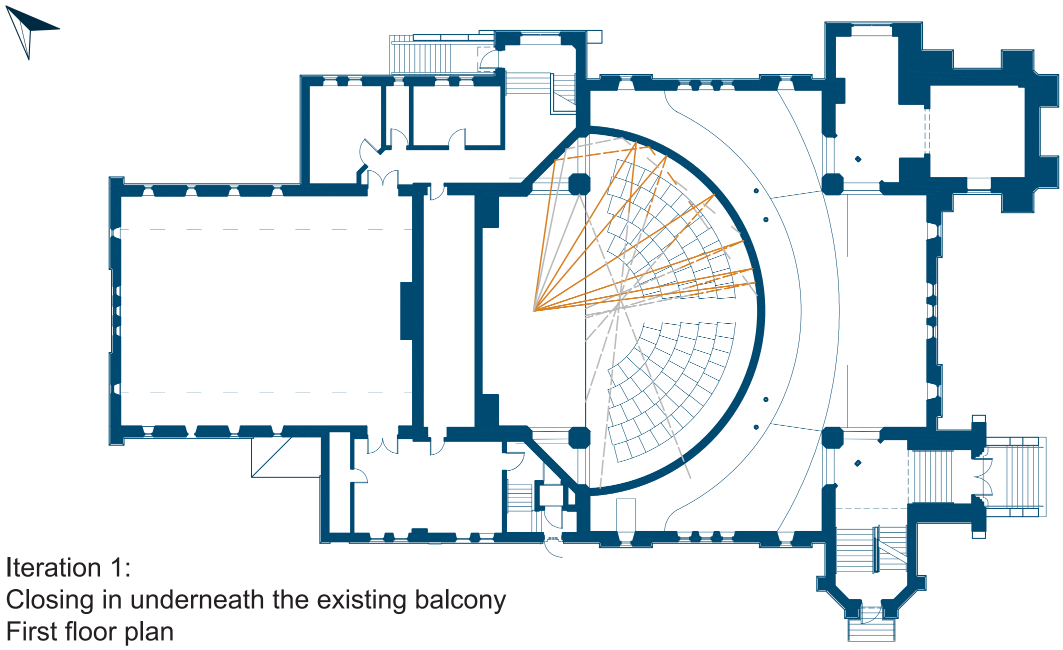
Interior rendering of proposed concert hall

This design for a concert hall and arts centre seeks to revive the connection between architectural space and choral music through its flexibility of choral configurations in the concert hall and adjustable acoustics. It also seeks to revive the community importance of the decommissioned United Memorial Church through the incorporation of a lobby and variety of rental spaces.

Renaming

I have renamed this building from the United Memorial Church to the Richmond Memorial Arts Centre. Removing the “church” label opens the building to a wider audience, as many members of Canada’s multicultural society do not feel comfortable entering churches due to religious or moral differences. Though I have largely focussed on the design of the building’s concert hall, the building is intended to be used for more than just concerts, also hosting office and rehearsal spaces for musical groups around the city. As such, I have named it as an arts centre, rather than concert hall.

The United Memorial Church’s denomination has also been removed from its new name, but “Memorial” is essential to be retained, reflecting the building’s significance in relation to rememberance of the Halifax Explosion. “Richmond” has been added to the building’s name as a link to the site’s past, and to recall collective memory of the area of Richmond.



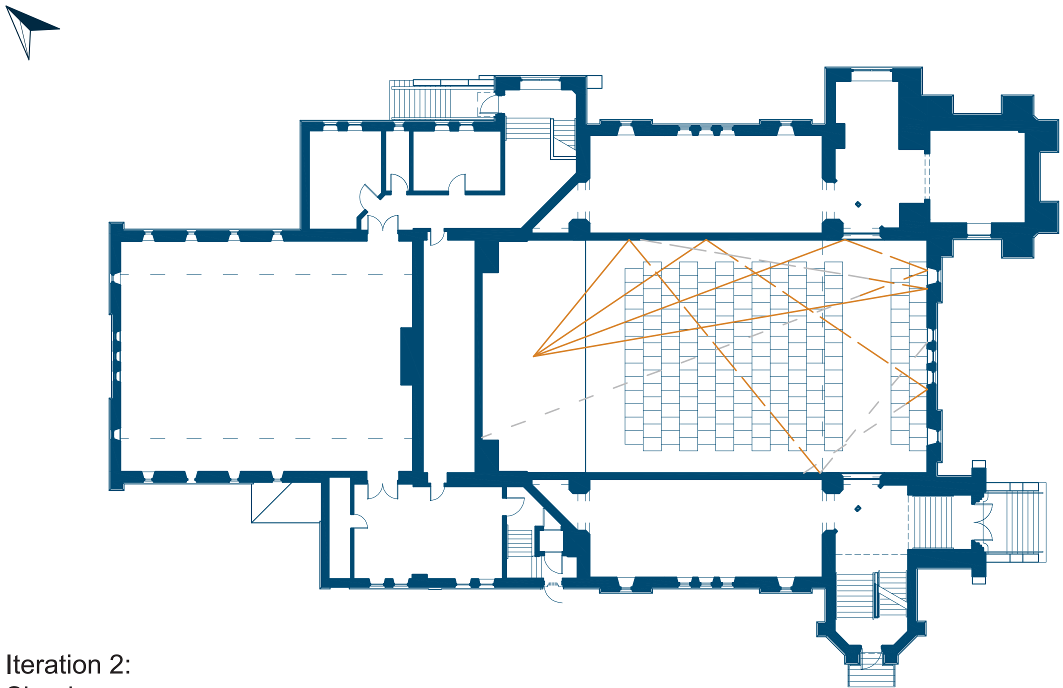
Iteration 1:
Closing in underneath the existing balcony
First floor plan
1:400

Early Iterations

In Cobb's original design, the balcony covers the majority of the first floor, and likely traps a significant amount of sound underneath. The balcony is therefore not appropriate for a concert hall, and redesigning it has been the most significant change to the hall. I therefore began the design process by testing various balcony configurations with Sabine's Law and ray tracing. To better compare the reverberation times, I used a standard set of materials. The full set of drawings and reverberation time calculations for these early design experiments can be found in Appendix D.

The first iteration, which simply closed off the area under the balcony, had the effect of focussing sound rays due to the concave nature of the semicircular balcony.

The second iteration was to fit a shoebox concert hall into the space. Ignoring the church's transepts, the length of nave is twice its width, which is the ratio of a shoebox hall. Ray digrams showed this plan to be extremely effective, as all first reflections bouncing off the sidewalls reached

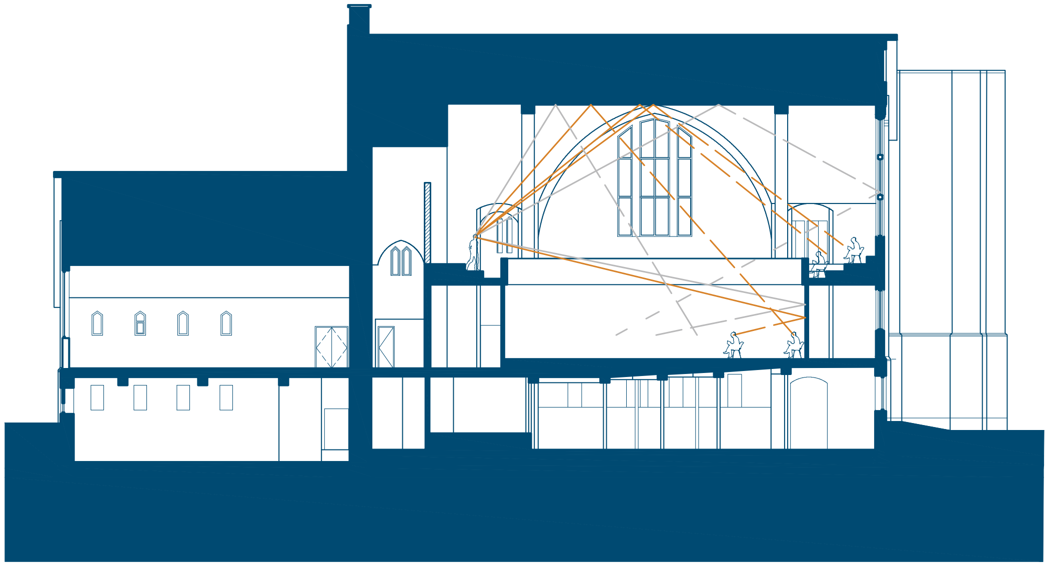


Iteration 2:
Shoebox
First floor plan
1:400

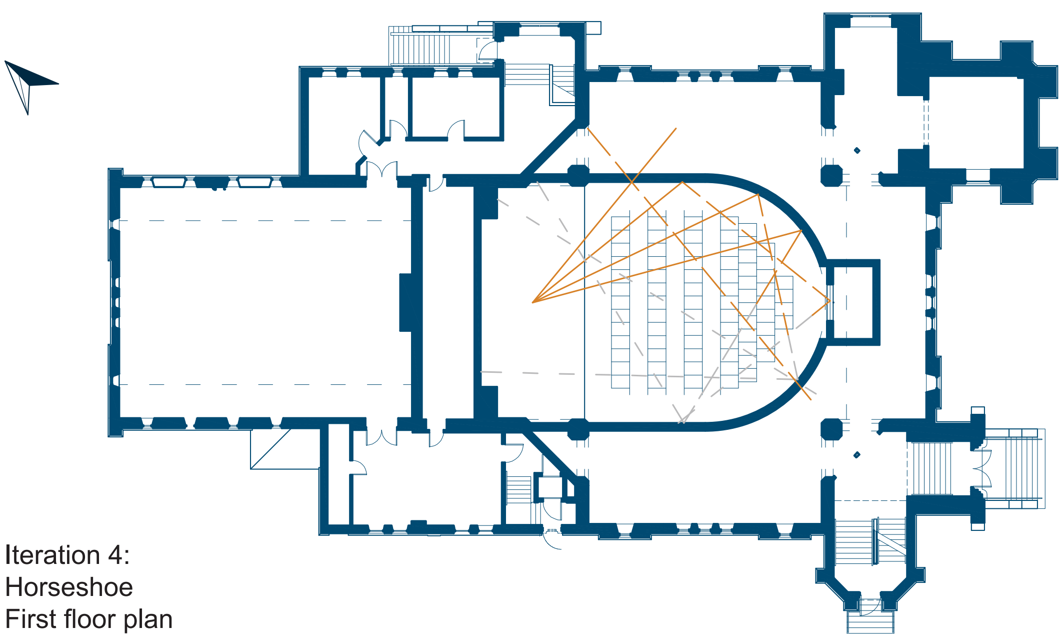
the other sidewall without the path difference exceeding 7 metres. This iteration also had the greatest seating capacity.

The third iteration was a circular plan, most similar to a vineyard type concert hall. This iteration showed the effectiveness of having the sound source come from above, but otherwise had many flaws, including the steep angle audience members would have to look up at to see the performers, and the concave nature of the circular plan. This plan could have developed hot spots acoustically and had a whispering gallery effect. It also had a surprisingly long reverberation time.

The fourth iteration was a horseshoe plan, inspired by Trinity-St. Paul's Church in Toronto. Like with the shoebox plan, the parallel sidewalls on the bottom floor were very effective at reflecting sound back to the audience. The second floor was



Iteration 3:
Circular
Longitudinal section
1:400

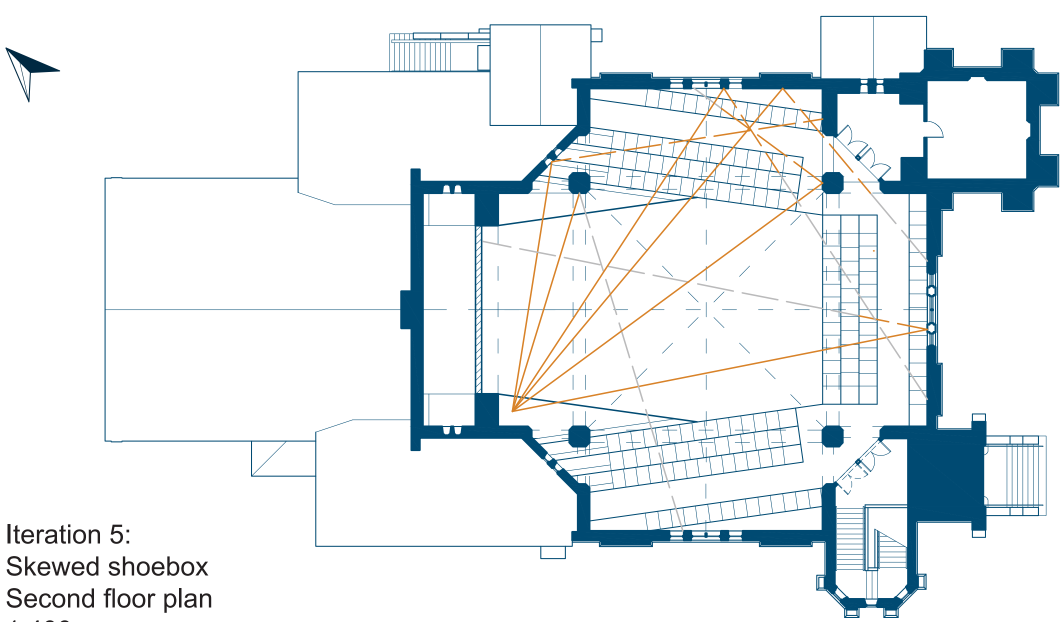


Iteration 4:
Horseshoe
First floor plan
1:400

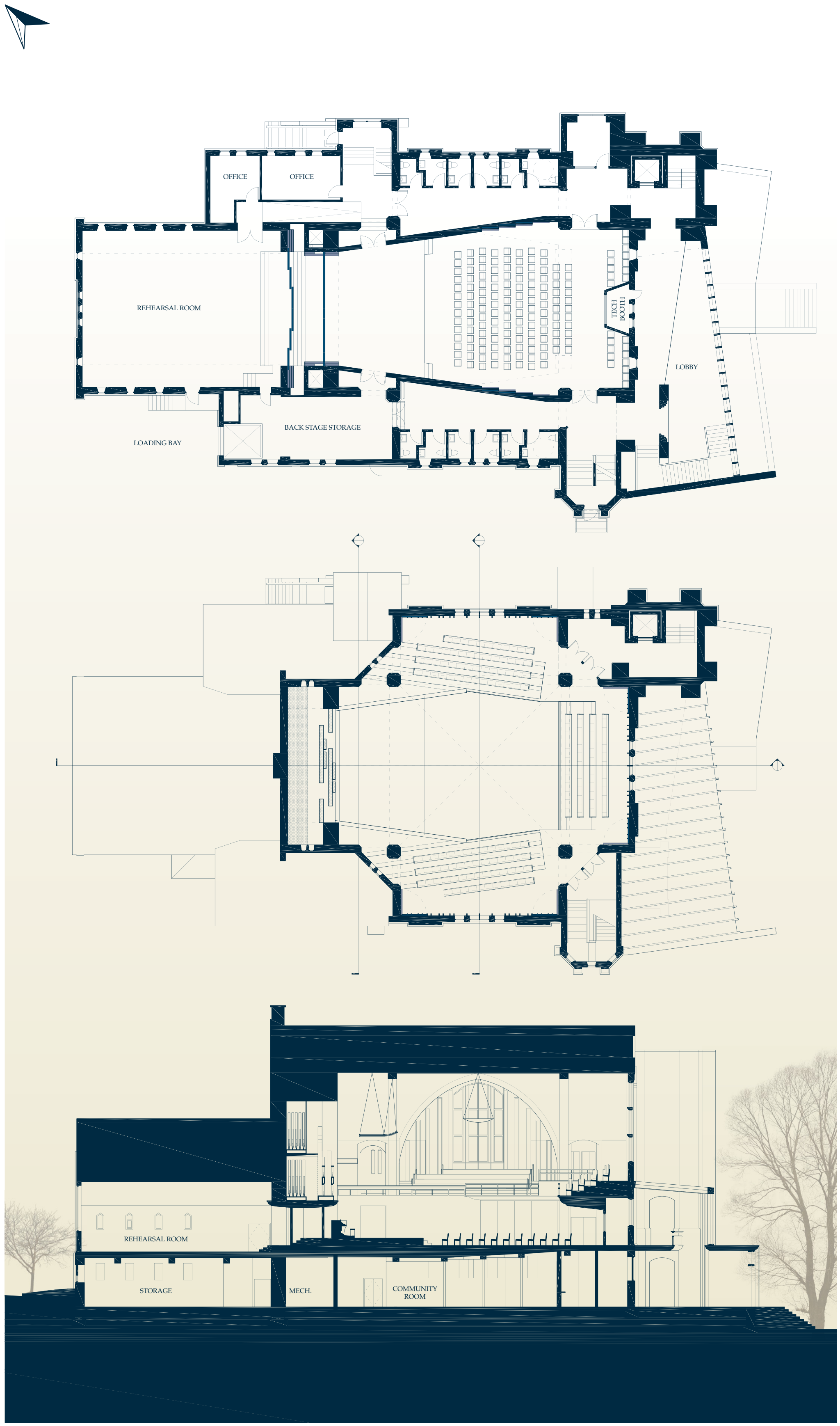
acceptable, though this iteration was not very effective in section.

From these four iterations, I had originally chosen the second option, the shoebox plan, due to how effective the sidewalls on the first floor were at reflecting sound. The section was not as effective, but could be improved with acoustic reflectors and cornices. The two transept balconies could be used for double choir music, such as Willaert's double choir psalms. The reverberation time was also very appropriate, between 2.28 seconds when empty and 1.88 seconds when full.

However, I did try one last iteration. Beginning from the shoebox plan, I rotated the first floor side walls outwards from the stage, but the transept balconies inwards. This created a pocket of balcony above the stage, and maintained similar ray diagrams, reverberation times, and seating capacities with the shoebox plan. In short, it maintained all the qualities that made the shoebox plan so effective, while adding new performance possibilities. I therefore selected this plan and developed it for my final design.



Iteration 5:
Skewed shoebox
Second floor plan
1:400



1st floor,
2nd floor,
Section
1:400

Concert Hall

As outlined in Chapter 4, I have designed the concert hall's acoustics through Sabine's Law and ray diagramming. These two methods revealed three main variables to building a room's acoustics: its form, the configuration of sound sources relative to the audience within the room, and the surface materials. In the following sections, I will outline what each variable contributes to this concert hall's design.

Form

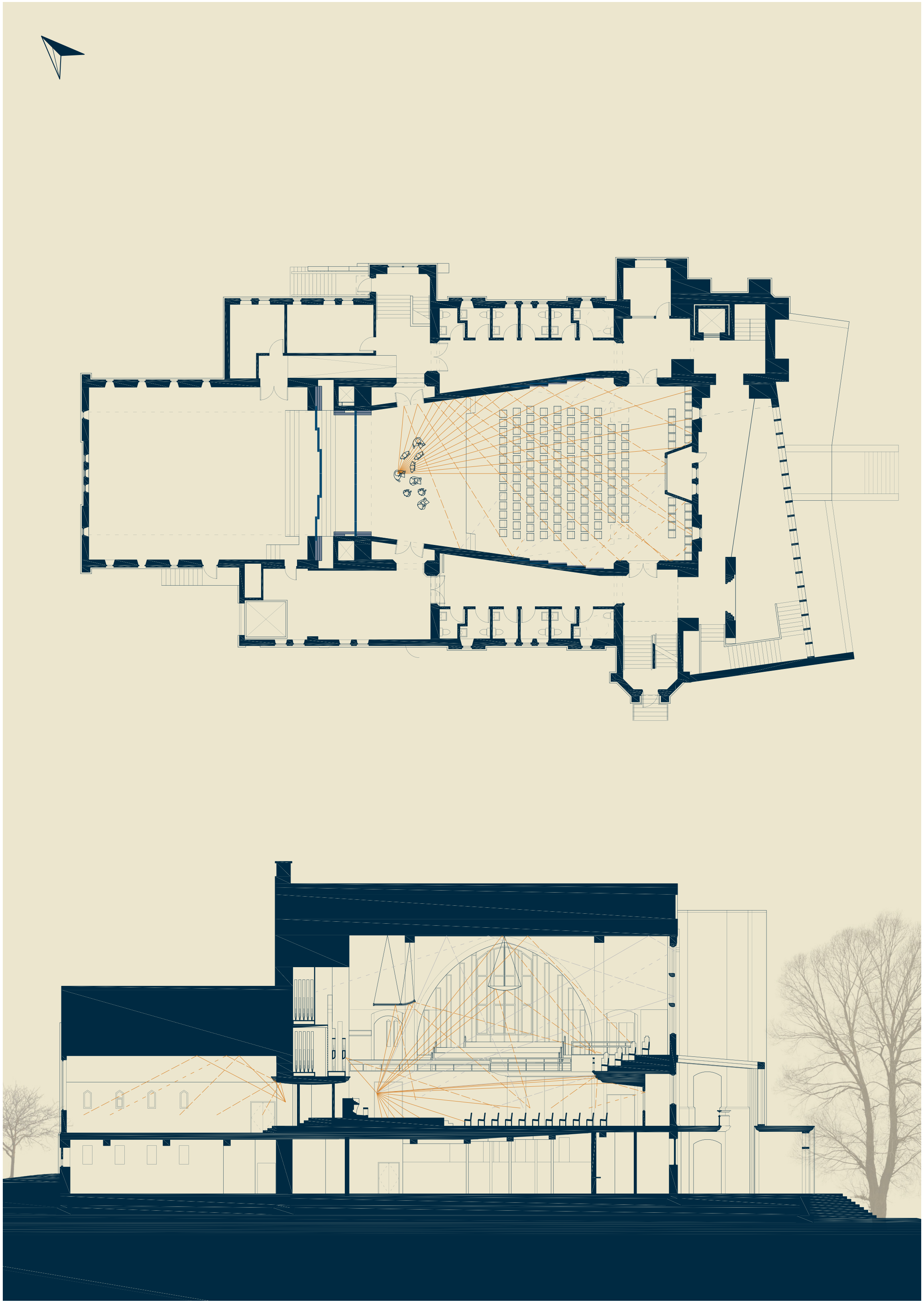
Between the existing and proposed designs, no structural walls have been modified, save the columns supporting the existing balcony. Though the bottom floor is largely a shoebox plan, the upper floor retains the Greek Cross aspects of its plan. Out of respect for the original architecture, I have maintained the groin vaulted ceiling. A control booth is located at the back of the bottom floor, enabling the room to be used for recording sessions as well as performances.

The side balconies are closed in underneath, precluding sound from getting trapped there. The back balcony is much less deep than the original and has an angled soffit to discourage sound from becoming trapped.

Sound Source Configuration

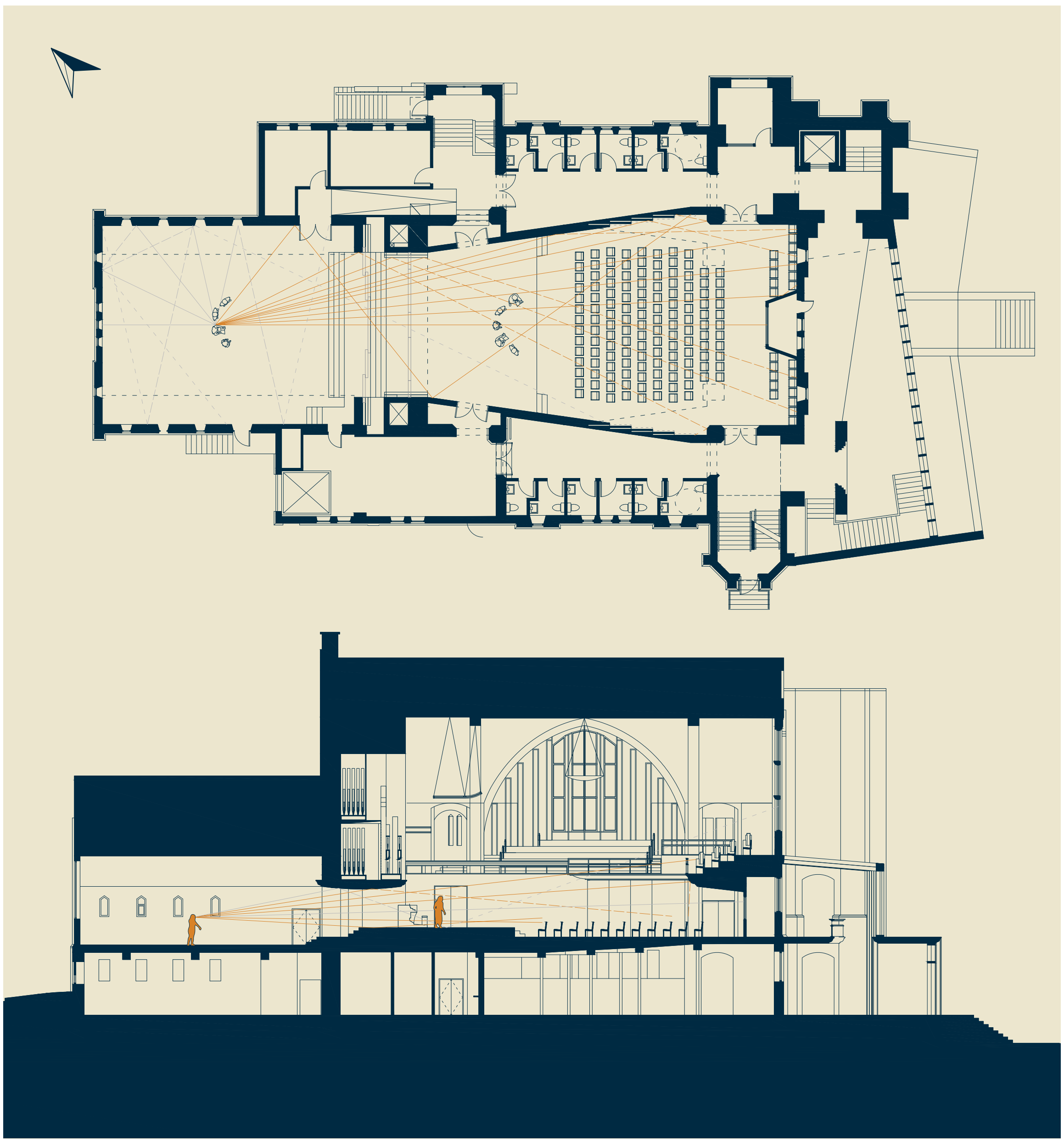
Performances From The Bottom Floor

Being based on the shoebox plan, the bottom floor of the concert hall is acoustically excellent for performances on the stage. All first reflections bouncing off the reflective sidewalls reach the audience with a path difference under 7 metres. Any show where all the performers are located on the stage can use this configuration to great success.



1st floor plan and longitudinal section with sound source on stage
1:400

The back wall of the stage can be opened up to connect the concert hall with the rehearsal room behind, enabling the rehearsal room to be used as an extension of the stage. This arrangement emulates retroquires, where the choir is located behind an altar and screen, and the congregation is unable to see the singers. The use of the back room is also useful for pieces which benefit from a contrast in acoustic



1st floor plan and section with sound sources in back rehearsal room
1:400

distances, such as Gregorio Allegri's setting of *Miserere Mei, Deus* and Benjamin Britten's *Hymn to the Virgin*. These two pieces can be performed with the principal choir on the stage and the secondary choir in the back rehearsal room. Additionally, this room can be used for processionals, such as David Willcocks' setting of the Advent Matins responsories. This piece is often performed with the choir beginning from afar (complementing the opening phrase of "I look from afar"), and the volume increasing as the choir approaches the audience. Such processionals are exciting and dynamic uses of architectural space that the back rehearsal room helps this concert hall to accommodate.

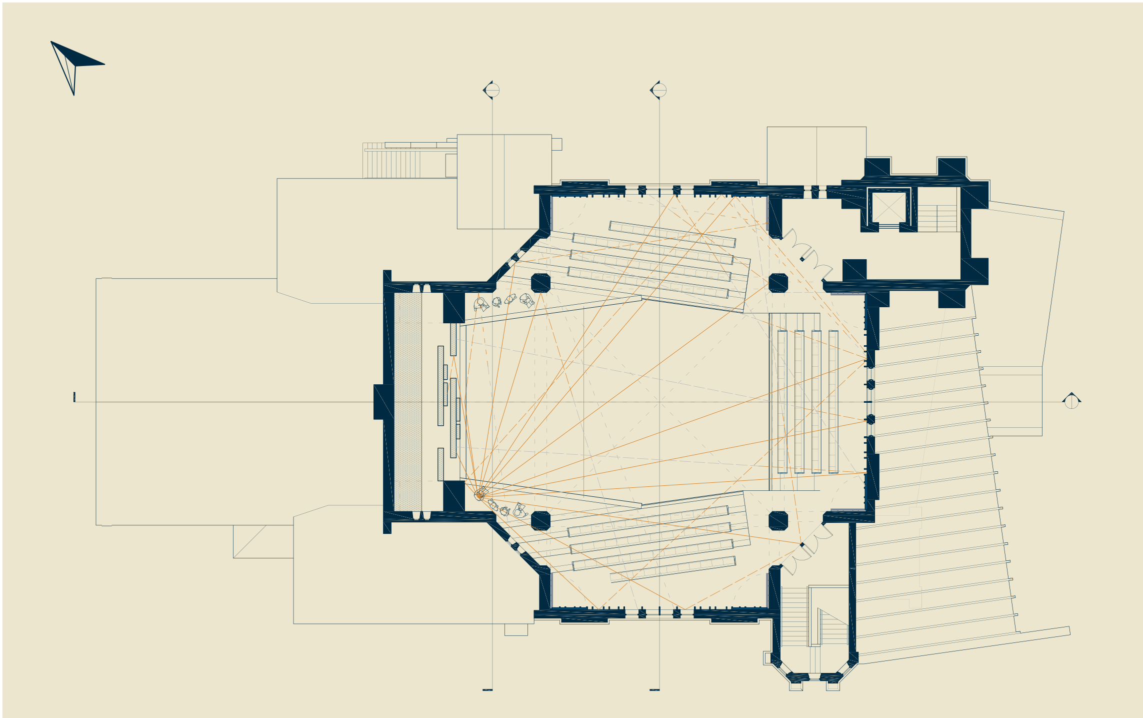
A reflective ceiling and side walls between the two rooms helps to bounce sound through this opening and into the concert hall. Due to the distance between the rehearsal room and audience, there are few issues of path difference exceeding Egan's recommended 7 metres.

Additionally, the slope to the bottom floor in the original design has been levelled out. This enables the chairs to be repositioned as per the performer's preference.

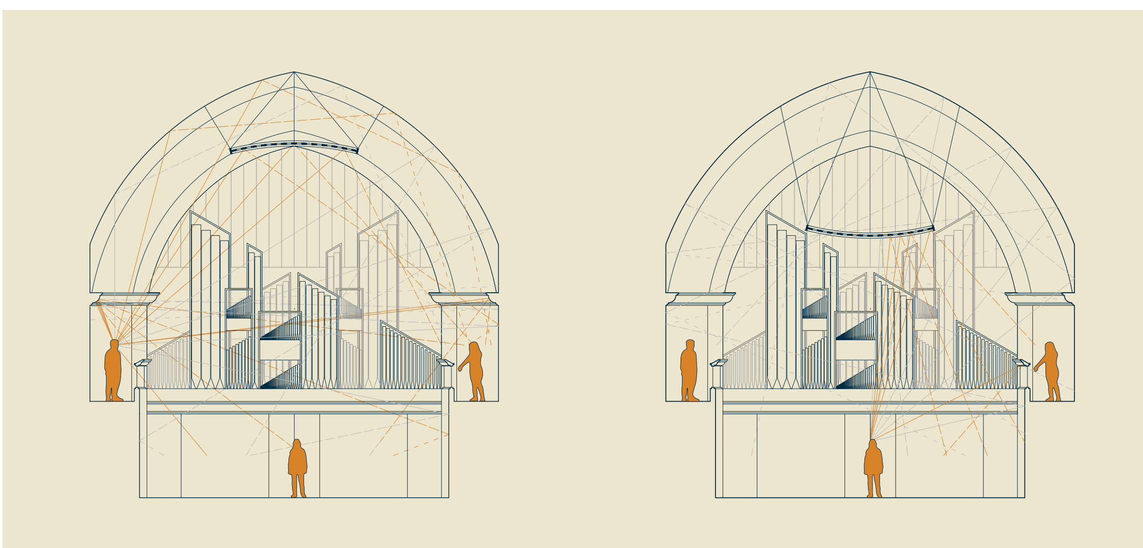
Performances from the Balconies

Any of the balconies can be used for performances for polychoral music, though the twin balconies over the stage are especially designed for such use.

The upper floor distributes sound well from the twin balconies. It is essential that choirs located in these two balconies and on the stage receive strong early sound from one another in order to keep the performers in time and tune with each other. To enable this, an acoustic reflector is hung from the ceiling between the twin balconies. When



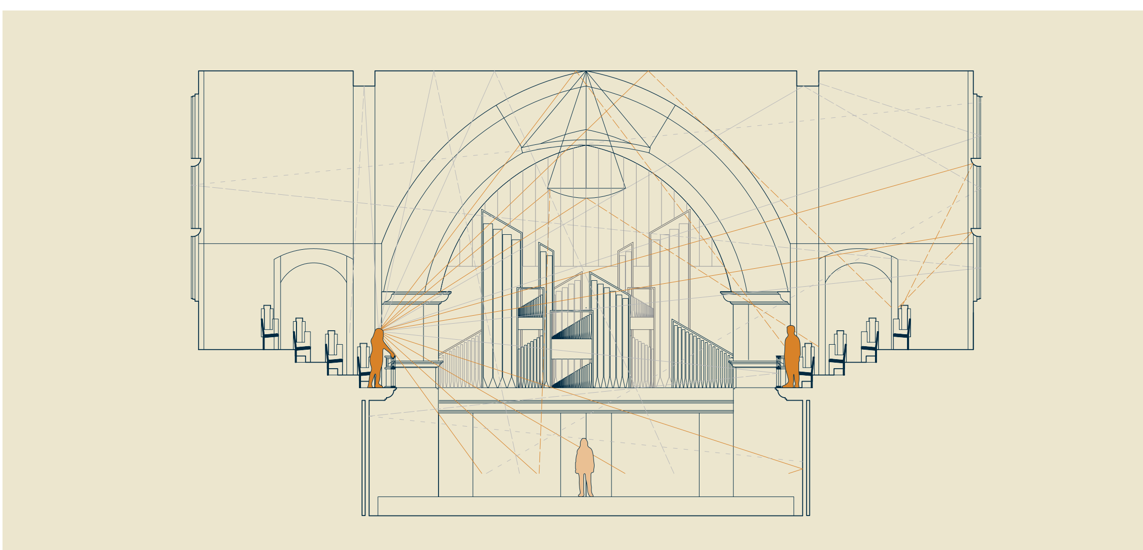
2nd floor, sound source in stage balcony
1:400



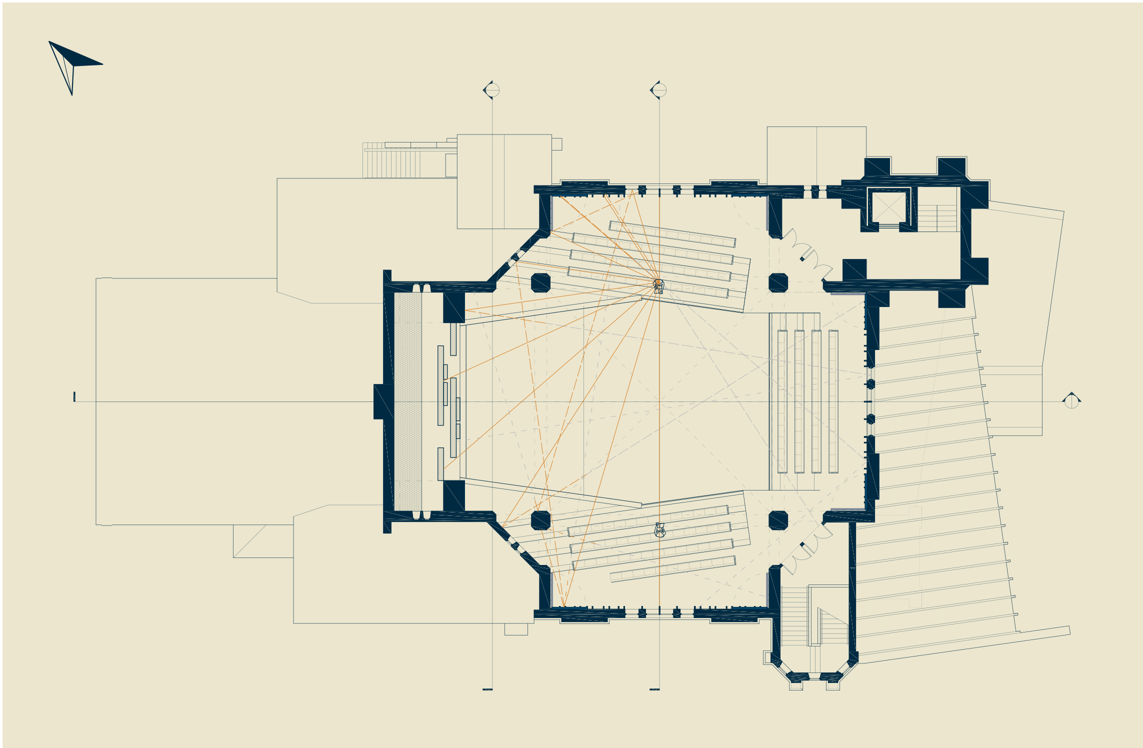
Left: Stage section with acoustic reflector raised
Right: Stage section with acoustic reflector lowered
1:300

bouncing sound from balcony to balcony, the reflector should be drawn upwards in a concave positioning. While such a concave position would focus sound on the stage, it is the most effective shape for bouncing sound between the balconies and keeping the path difference below 7 metres. When performers are also on the stage, this reflector should be moved downwards and positioned in a convex orientation. This position distributes sound equally from the balcony across the stage, while keeping the path difference of sound moving from the balcony to the stage acceptably short.

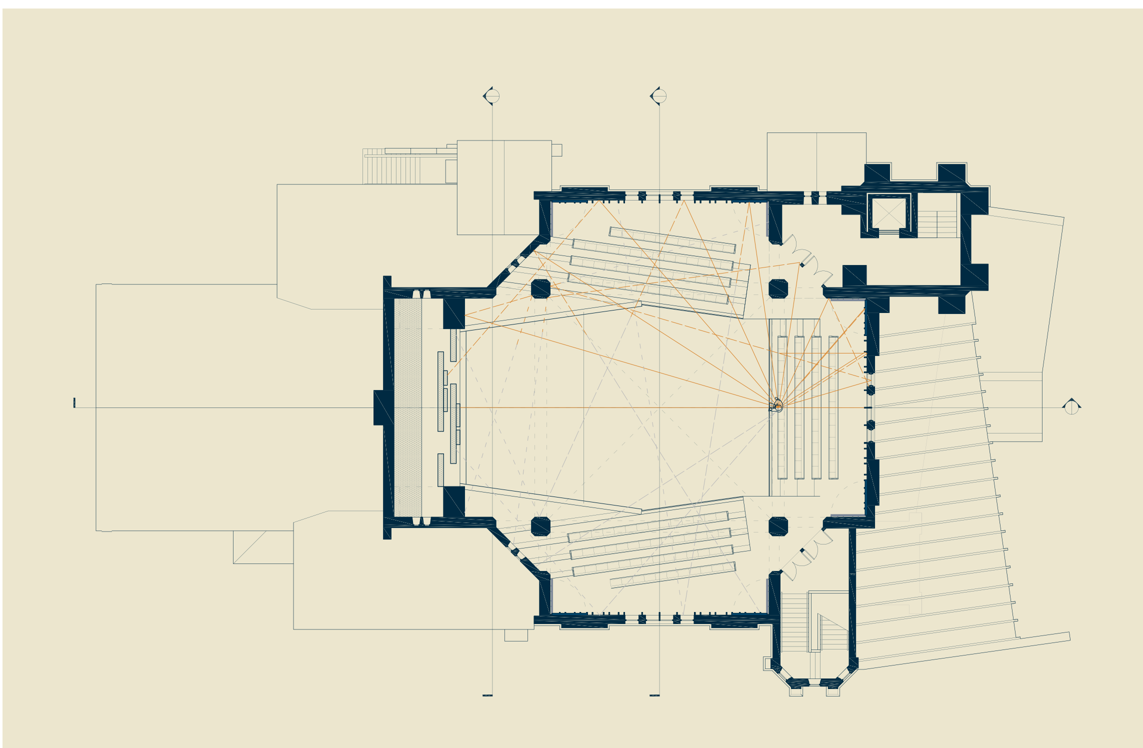
The other balconies are also usable for performances with more than two choirs, such as Heinrich Schütz's *Psalmen Davids*, which includes compositions for up to four choirs. The height of these balconies is disadvantageous for the audience's sightlines, as they would have to look up at a sharp angle at the performers, but is effective acoustically, as the audience receives more early reflections with the steep angle that sound falls at.



Lateral section, sound sources in side balconies
1:300



2nd floor, sound source in transept balcony
1:400



2nd floor, sound source in back balcony
1:400

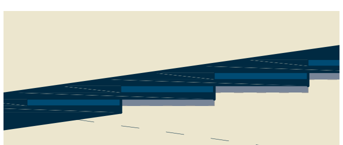
Interior of the King's Chapel, as seen from the choir stalls

Materials

The concert hall's materiality is the last piece of its acoustic puzzle. I have drawn its material palette from the existing architecture, Andrew Cobb's other churches, and from Art Deco design, which this church is an early example of.

Cobb's church naves typically have the lower part clad in wood (wood floors, pews, and wall panelling) and the upper part surfaced in plaster. This division is especially evident in King's, which has wooden choir stalls. I have retained that here, with the exception of brick side walls. These sidewalls seek to draw in the materiality of church's exterior, echoing the brick panels of the upper parapet. Brick is an appropriate choice for sidewalls, being both reflective and irregular, following Egan's recommendations (1988, 125). Brass cornices and vertical fins on the gable ends serve to reflect and disperse sound respectively. On the back wall particularly, the fins inhibit any slap back echoes from distracting performers on the stage.

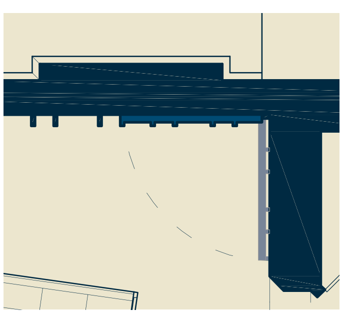
Acoustically absorptive surfaces include the back wall under the balcony, the upholstered chairs, and the audience. The audience is the most substantial acoustic absorber in the room.



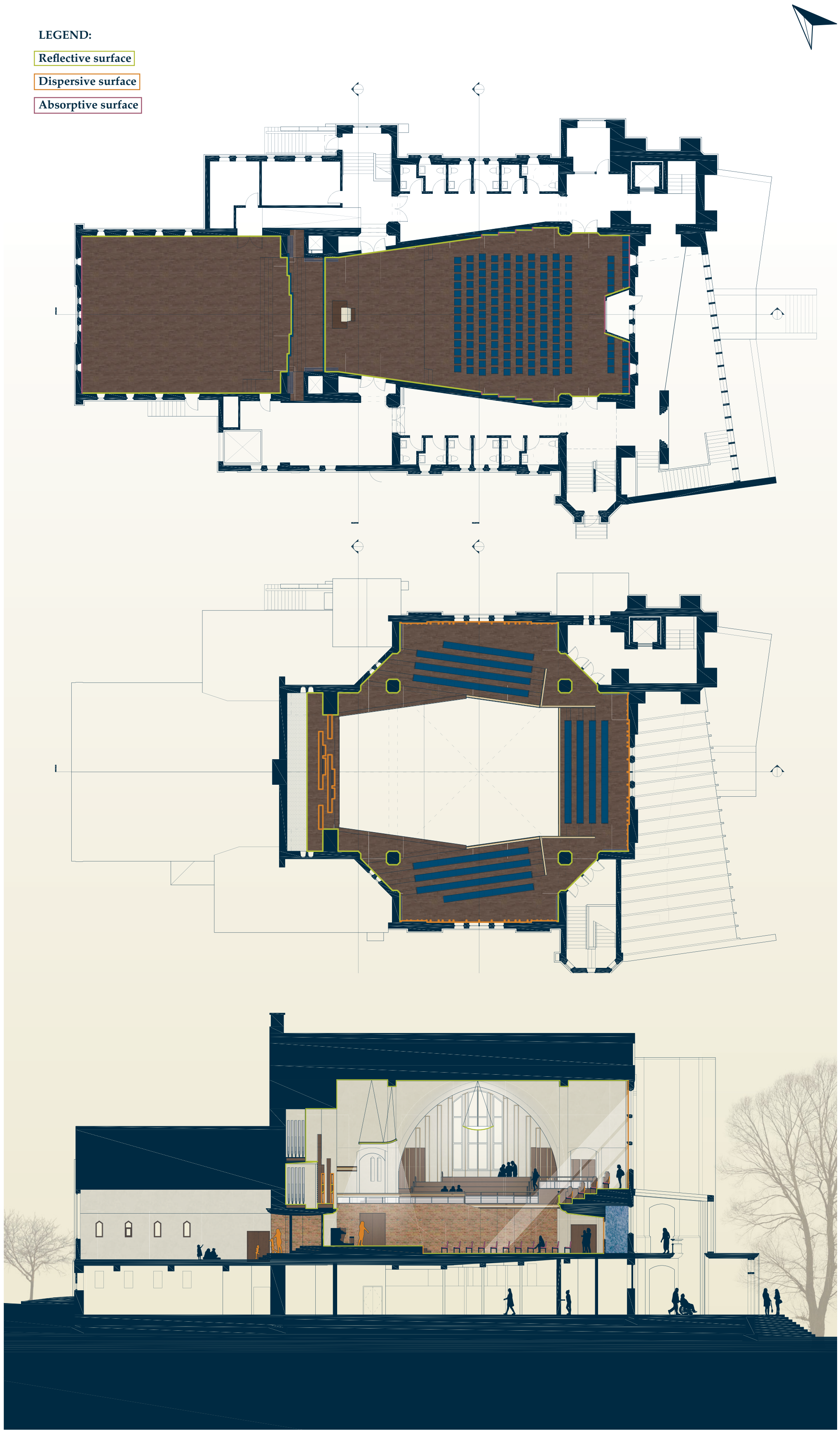
1st floor sliding panels
1:100

Adjustable Acoustics

I have incorporated two elements to adjust the room's reverberation time. On the bottom floor, sliding acoustic panels can be drawn out from the side walls to cover the brick, thereby lowering the reverberation time. On the upper floor, rotating panels swing out from the back wall. One side of these panels is covered with thick wood, which is



2nd floor rotating panels
1:100



Acoustic material qualities

1st floor, 2nd floor, Section 1:400

acoustically reflective, while the other side is clad in acoustic panelling.

Reverberation Time

The final reverberation time is:

RT60	**Empty (seconds)**	**Full (seconds)**
Acoustic panels set to reflective sides and back room open	2.41	1.94
Acoustic panels set to reflective sides	2.51	1.92
Acoustic panels set to absorptive sides	1.94	1.57

The scenario with the acoustic panels set to the reflective sides meets my goal of achieving an RT60 of 2 seconds when partially full. I had intended for this to be able to be varied up or down depending on the performer’s preference. The acoustic absorbers do succeed in decreasing the RT60 down to a level more appropriate for orchestral music. However, adding volume to the concert hall through the back room was not succesful in increasing the reverberation. The full RT60 calculations can be found in Appendix E.

Bass Ratio

The final bass ratio is:

Bass Ratio	**Empty**	**Full**
Acoustic panels set to reflective sides and back room open	0.85	0.98
Acoustic panels set to reflective sides	0.98	1.13
Acoustic panels set to absorptive sides	1.21	1.32

When the acoustic panels are turned to their absorptive sides, Egan's recommended bass ratio of 1.2 is met. When they are on the reflective side, the room falls short of this goal, though not by far when it is full of audience members.

Lessons Learned

While I largely met my goals acoustically, there are some areas where I did not meet them, as well as further ways that the room's acoustics could be improved. For the benefit of posterity, I will detail these lessons.

Firstly, it would be much simpler to employ retractable curtains instead of panels in order to manipulate the reverberation time. This method is employed in Dalhousie University's new Strug Concert Hall, and can be easily modified, even during intermissions of concerts. This method is also time tested, with tapestries having been used in churches to decrease reverberation times during the Renaissance. They also offer a greater flexibility of reverberation time than panels, as they can be pulled only halfway across a wall, for example, rather than having to be completely rotated, as in the case of my upper floor absorbers.

Secondly, I learned that adding volume to a room is not an easy way to increase reverberation time, as that extra volume also comes with extra surface area. In adding the back rehearsal room's volume and surface areas to my calculations, I actually decreased the reverberation time when the rooms are empty, rather than increasing it, as I had intended. I have consequently learned that the ratio of additional volume to additional surface area matters when attempting to use volume to increase reverberation.

Finally, I found that the majority of my issues with path differences exceeding 7 metres, or even Egan's permissible 10 metres, were caused by the church's ceiling. In this design, I have retained the ceiling largely out of respect for the original architecture, and indeed, one of my colleagues recognized the church in my interior renderings based solely off the ceiling. Knowing now that the concavity, height, and smoothness of the ceiling would all cause issues acoustically, I would not be so precious about keeping the ceiling as is. Though as a conservationist I value respecting original architectural intent, the ceiling has too big an effect on the room's acoustics to choose to be unquestioningly precious about that architectural element.

Urban Strategy

The Richmond Memorial Arts Centre spans a full city block, and consequently has frontage on both Kaye and Young Street. The existing building's main entrance is on Kaye Street, which seems odd, as Kaye is a residential street and Young Street a minor arterial road, which connects four major arteries together before turning into a provincial highway.

However, Young Street used to be discontinuous between Isleville and Gottingen Streets, making Kaye Street the more major of the two. Indeed, the original Methodist church on the site fronted onto Kaye Street (as its name, Kaye Street Methodist Church, demonstrates).

The Richmond Memorial Arts Centre will continue the United Memorial and Kaye Street Methodist churches' tradition of fronting onto Kaye Street, reflecting the street's former purpose as an artery. The lobby addition is accessed via Kaye. However, the loading bay is accessed via Young

Plan of the devastated areas of Halifax following the Explosion. Note discontinuity of Young Street across Gottingen Street. (N.S. Board of Insurance Underwriters 1918)

Street, keeping large trucks accessing the building on the larger and louder of the two roads.

Arts Centre

Lobby

A new lobby addition invites people in from Kaye Street. Located on level with the basement, this lobby has easy access to the elevator, and contains a box office and a small bar. A balcony extends between the bell tower and the gabled structure that contains the existing entrance. Encapsulated by the new lobby, this structure is reframed as the entrance to the concert hall, and is accessed by a staircase and the aforementioned balcony.

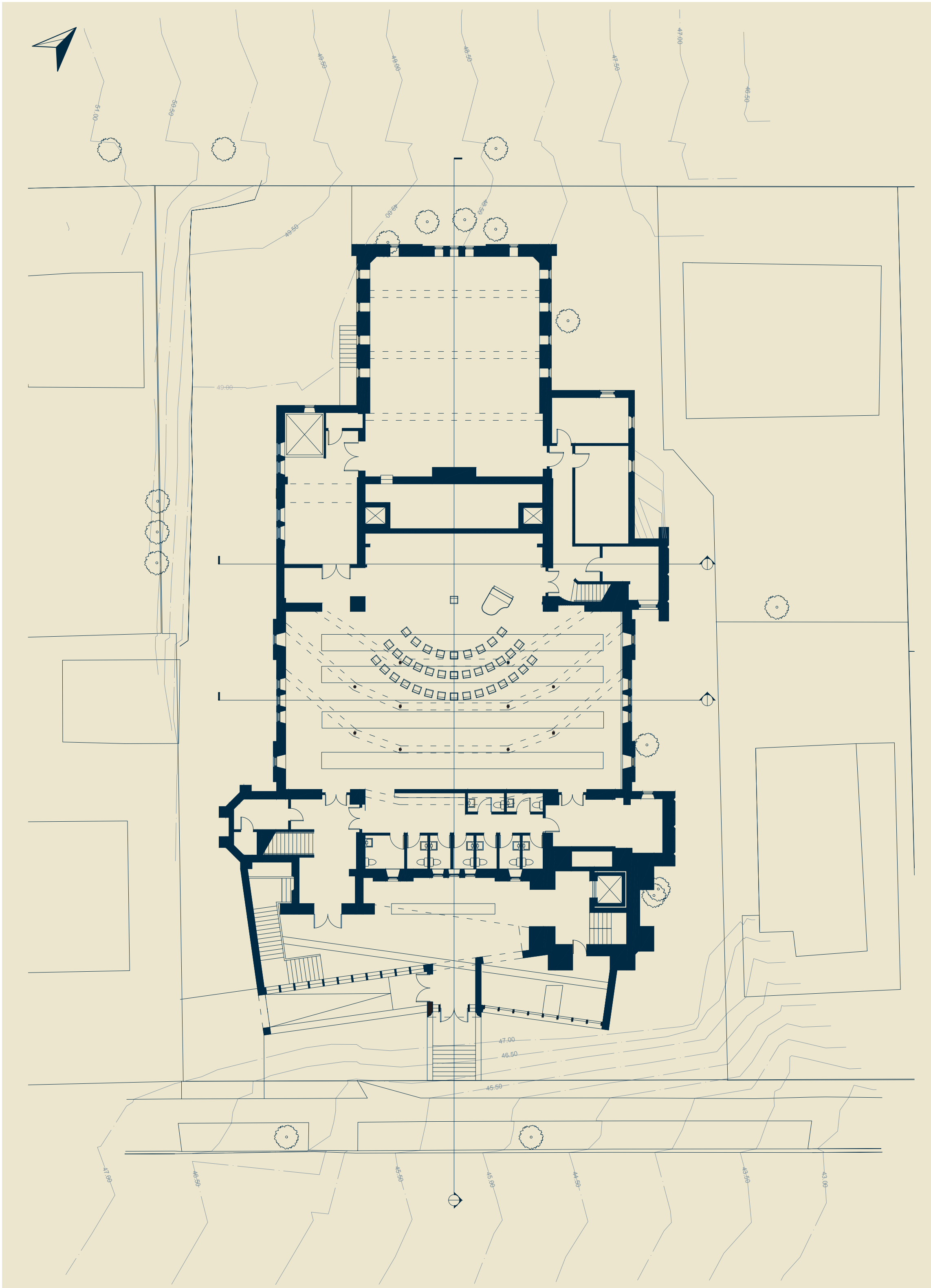
In addition to welcoming people to the arts centre, this inviting lobby serves a critical community role by encouraging informal gathering before and after concerts. Audience members who know performers typically tarry in the lobby of concert halls to congratulate and discuss the concert with performers, which this lobby enables.

Rentable Rooms

In addition to the concert hall, the Richmond Memorial Arts Centre houses rentable rehearsal and office spaces for arts organizations. This will allow the building to help foster and support the city's arts organizations, as Trinity-St. Paul's and St. Andrew's churches do in Toronto and Halifax respectively.

Community Room

Multiple online sources about the United Memorial Church mention how the church's basement was used for bowling, as well as for Girl Guides groups. I have improved access



Site and basement plan
1:400

from the building’s entrance to this basement room, encouraging its use by such community groups. Bowling alleys can still fit in the modified basement room. This space can also accommodate orchestra rehearsals.

During performances, this room can function as the holding area for performers not on stage, with easy access to bathrooms, a makeup counter, and multiple staircases up to the concert hall.

Bathrooms

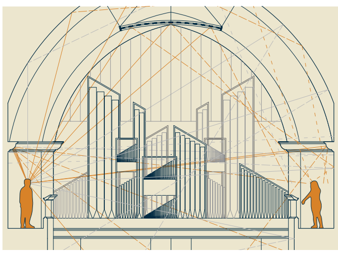
It is my experience as a performer that there should be a separate set of bathrooms for performers and for audience members. This saves performers from panicking in long bathroom lines shared with audience members during intermissions. Prior to a concert, I once walked a block from a church back to my school because it was faster than waiting in line. Additionally, I have yet to sing in a church or concert hall with too many bathrooms. As such, I have significantly exceeded the *National Building Code of Canada*’s recommendation of how many bathroom this building requires, and designed two sets of bathrooms. The first is adjacent to the concert hall, and the second is adjacent to the performers’ holding area.

Other Instruments

While the concert hall has primarily been designed with choral music in mind, it must also accommodate other instruments, especially those which typically accompany choirs, such as pianos and organs.

A service elevator is accessed from Young Street to transport heavy instruments between the basement rehearsal room and concert hall level. This elevator and all

Keith Graham, Halifax Explosion Memorial Bell Tower, Halifax, Canada, 1985



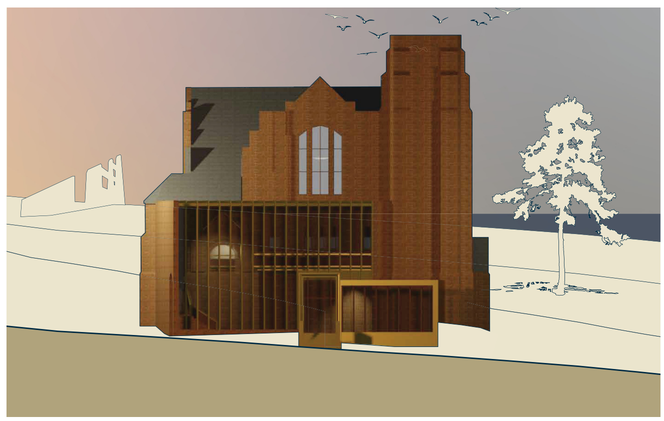
New organ screen

doorways between it, the rehearsal room, and concert hall accommodate the width of a grand piano.

The existing pipe organ has been retained, but its console and screen redesigned. The console is detachable, enabling it to be moved around the stage to the performers' preference. Shafts through the concert hall walls connect the organ's wind chest to a fan in the mechanical room immediately below, minimizing the bends in the shaft to reduce sound produced by wind and fans. The design of the organ screen mimics the form of the Memorial Bell Tower atop Fort Needham, connecting the concert hall to the building and site's heritage.

Concert hall rendering

New lobby rendering overlaid over historic photograph



Front elevation rendering

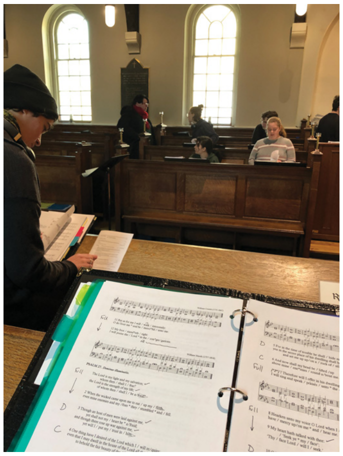
Stage balconies in use for double choir music

Chapter 7: Conclusion

Though normative concert halls limit the performance of choral music, which has adapted to mitigate and benefit from the acoustics of churches, they can be better designed to suit choral music by incorporating flexible reverberation times and sound source locations. Retrofitting decommissioned churches into concert halls is an ideal partnership between the typologies of churches and concert halls that serves the needs of choral music, as well as the communities that house these buildings. The adaptive reuse of churches in this fashion enables the heritage and community value of these buildings to be maintained, while the introduction of new uses ensures that they maintain their importance and vitality. Often located in the hearts of cities, these structures are accessible to a wide swathe of a city's population, just as the voice is the most widely accessible instrument.

The United Memorial Church proved an ideal site on which to test this thesis. Steeped in historic value as a memorial to the Halifax Explosion and located in an accessible area of Halifax, its form lends itself well to accommodating a concert hall with adjustable reverberation times and performance orientations. Though my methodology of employing Sabine's Law and ray diagrams to build the proposed concert hall's acoustics were effective for a student design, I was not able to test whether these acoustics were successful off paper. Professional design of such concert halls should make use of specialized acoustic modelling software. Other students studying this subject would benefit from affordable, educational access to such software.

Though this thesis has formally occupied a ten-month period, this study has been years in the making, drawing



View of the King's Chapel from within the choir

Quire of All Saints Cathedral

on information gleaned in previous undergraduate and graduate classes, and eighteen years in choirs. A prior class on heritage conservation and experience singing double choir and polychoral music in Haligonian church choirs have been especially vital to this thesis. My research of the majority of the Canadian churches and concert halls discussed in this thesis was done experientially by occupying them as a singer, providing me with the perspectives of both architect and performer, designer and inhabitant. Even the acoustic commissioning of Dalhousie's new Strug Concert Hall, which I attended intending to listen and learn from the acousticians present, I instead ended up singing at.

Residing in between the subjects of architectural history, adaptive reuse, musicology, and architectural acoustics, this thesis is highly interdisciplinary. I am indebted to the expertise of my thesis committee, which was comprised of an architect specializing in adaptive reuse, a musicologist, and an acoustician. The subject of the interrelation of church architecture, music, and acoustics is best approached in an interdisciplinary manner, as demonstrated by Deborah Howard and Laura Moretti in their study of Venetian churches, *Sound & Space in Renaissance Venice*. Katelijne Schiltz writes that musical composition is "an activity that always needs to be situated in a clearly determined context" (2003, 75). Acoustics and architectural space form an essential part of this context. Similarly, the music performed within churches is beneficial context to understanding these buildings, with Howard and Moretti writing that restoring "the aural quality to celebrated masterpieces of church design adds a crucial dimension to the understanding of their original impact and enhances our own experience of these spaces today" (2009, 203).

This thesis began as an undergraduate paper boldly attempting to answer the question of the degree to which late Renassiance architects designed churches for choirs. Three years later, I still have found few answers to this question. I have developed a typology of quires to facilitate further research into how architects designed locations for choirs within churches. In terms of architectural acoustics, its evolution is well documented in relation to theatres, opera houses, and concert halls, but not well documented for churches, though they have housed music for longer than opera houses and concert halls combined. This gap in research would benefit from archival research into first-hand accounts of church design. Though none of the famous treatises on architectural design from the Renaissance (such as Sebastiano Serlio's *Seven Books of Architecture*) discuss church acoustics, letters such as Fra Francesco Zorzi's do, and perhaps there are more like it. I have also found further avenues of research closer to home and the present in the acoustic design of William Critchlow Harris. For an architect from a small province of Canada to master architectural acoustics to such a degree without simply emulating extant successful designs suggests that Victorian architects had a greater knowledge of acoustics than they are typically given credit for.

I will conclude this thesis as it began: in the silence of a (neo-)Gothic cathedral. Unlike Juhani Pallasmaa, I am not reminded of the last dying note of a Gregorian chant. Instead, I am reminded of how glorious it is to sing chant in so reverberant a space, with the building carrying the ancient sound on and on, as though the building itself were singing.

Ralph Adams Cram, All Saints Cathedral, Halifax, Canada, 1910

Appendix A: Glossary

Acoustical

Bass ratio	The ratio of reverberation time (RT60) at low frequencies to those at mid-frequencies.
Early-to-late energy ratio	This ratio compares the intensity (in decibels) of early sound to late sound in reverberation (Beranek 1992, 32).
Low frequencies	125 to 250 Hz.
Mid-frequencies	500 to 1000 Hz.
Pitch	The frequency of a musical note, measured in Hertz (Hz). Ex: A_4 = 440 Hz
RT60	Time in seconds it takes for a sound to decay by 60 dB; the standard of measurement of reverberation time.
Stereophonic	Recording which uses "two or more channels of transmission and reproduction so that the reproduced sound seems to surround the listener and to come from more than one source" (Oxford English Dictionary 2023, "Stereophonic").

Architectural

Chancel	The part of a church that contains the altar and often quire.
Nave	"The principal and central part of a church... that part of the church intended for the general public" (Burden 2002, 219).
Plan	Floorplan of a building.
Section	Cross-section of a building.
Transept	In a cruciform church, the space that crosses the nave. Can refer to this space in its entirety, or just to the arms of the cross.

Musical

Alto	Second highest choral part. Abbreviated as "A".

Antiphony	Music, especially church music, which is "sung, recited, or played alternately by two groups" (Oxford English Dictionary 2023, "Antiphonal"). Deriving from Greek *anti*, meaning "in reponse", and *phon*, meaning "sound."
Bass	Lowest choral part. Abbreviated as "B".
Cantoris	One of the two sides of a choir in a split chancel; this is the side occupied by the cantor. Typically, *cantoris* sits on the north side of an Anglican church. Often shortened to "can."
Coro Spezzato	Double, spatially divided choirs.
Decani	One of the two sides of a choir in a split chancel; this is the side occupied by the dean. Typically, *decani* sits on the south side of an Anglican church. Often shortened to "dec."
Homophony	Music which is "characterized by the movement of accompanying parts in the same rhythm as the melody." (Oxford English Dictionary 2023, "Homophonic").
Maestro di capella	Italian word for "choir master."
Pitch	The frequency of a musical note, measured in Hertz (Hz). Ex: A_4 = 440 Hz
Polychoral	"A polychoral work or passage is one in which the ensemble is consistently split into two or more groups, each retaining its own identity, which sing separately and together within a through-composed framework in which antiphony is a fundamental compositional resource." (Carver 1988, xvi)
Polyphony	"The style of [music] simultaneously combining a number of parts, each forming an individual melody and harmonizing with each other" (Oxford English Dictionary 2023, "Polyphony").
Tenor	Second lowest choral part. Abbreviated as "T".
Soprano	Highest choral part. Abbreviated as "S".

Appendix B: Recommended Listening

Stereophonic Music

Antiphonal Music

Britten, Benjamin. 1930. “A Hymn to the Virgin.”

- Suggested recording: The Cambridge Singers, 1988, *Faire is the Heaven – Music of the English Church*. Collegium Records COLCD107.
- Recorded in the Lady Chapel of Ely Cathedral, Ely, United Kingdom.

Gibbons, Orlando. 1622. “O Clap Your Hands.”

- Suggested recording: The Cambridge Singers, 1988, *Faire is the Heaven – Music of the English Church*. Collegium Records COLCD107.
- Recorded in the Lady Chapel of Ely Cathedral, Ely, United Kingdom.

Handl, Jacob. 1587. “Duo Seraphim.”

- Suggested recording: University of King’s College Chapel Choir, 2014, *Let Us Keep the Feast*.
- Recorded in All Saints Cathedral, Halifax, Canada.

Wood, Charles. 1919. “Hail Gladdening Light.”

- Suggested recording: The Cambridge Singers, 1988, *Faire is the Heaven – Music of the English Church*. Collegium Records COLCD107.
- Recorded in the Lady Chapel of Ely Cathedral, Ely, United Kingdom.

Polychoral

Monteverdi, Claudio. 1610. “Duo Seraphim.”

- Suggested video: The Monteverdi Choir, 1990, “Vespro della Beata Vergine”, 30:00, https://www.youtube.com/watch?v=QJIwFO9A1f8&t=4829s.
- Filmed in San Marco, Venice, Italy.

Schütz, Heinrich. 1650. “Saul, Saul, was verfolgst du mich?”

- Suggested recording: Cappella Murensis and Les Cornets Noirs, 2012, *Polychoral Splendour: from the four galleries of the Abbey Church of Muri*.
- Recorded in Muri Abbey, Muri, Switzerland.

Schütz, Heinrich. 1619. “Alleluja.”

- Suggested recording: Cappella Murensis and Les Cornets Noirs, 2012, *Polychoral Splendour: from the four galleries of the Abbey Church of Muri*.
- Recorded in Muri Abbey, Muri, Switzerland.

Tallis, Thomas. 1570. “Spem in alium.”

- The best experience of *Spem in alium* is Janet Cardiff’s sound sculpture, *40 Part Motet*, locating in the National Gallery of Canada. That being an airplane ride away, the recording below shall suffice for providing a surround sound experience.
- Suggested recording: The King’s Singers, 2012, *Thomas Tallis: Spem in Alium*.
- Recorded in Angel Studios, London, United Kingdom, with six singers singing the 40 parts non-simultaneously, then remixing the recordings together.

Willaert, Adrian. 1555. “Lauda Jerusalem Dominum.”

- Suggested recording: Capilla Flamenca, 2012, *Adriaen Willaert: Vespro della Beata Vergine.* Ricercar RIC325.
- Recorded in the Kapel Zusters van Sint Vincentius, Gijzegem, Belgium

Willaert, Adrian. 1555. “Laudate pueri Dominum.”

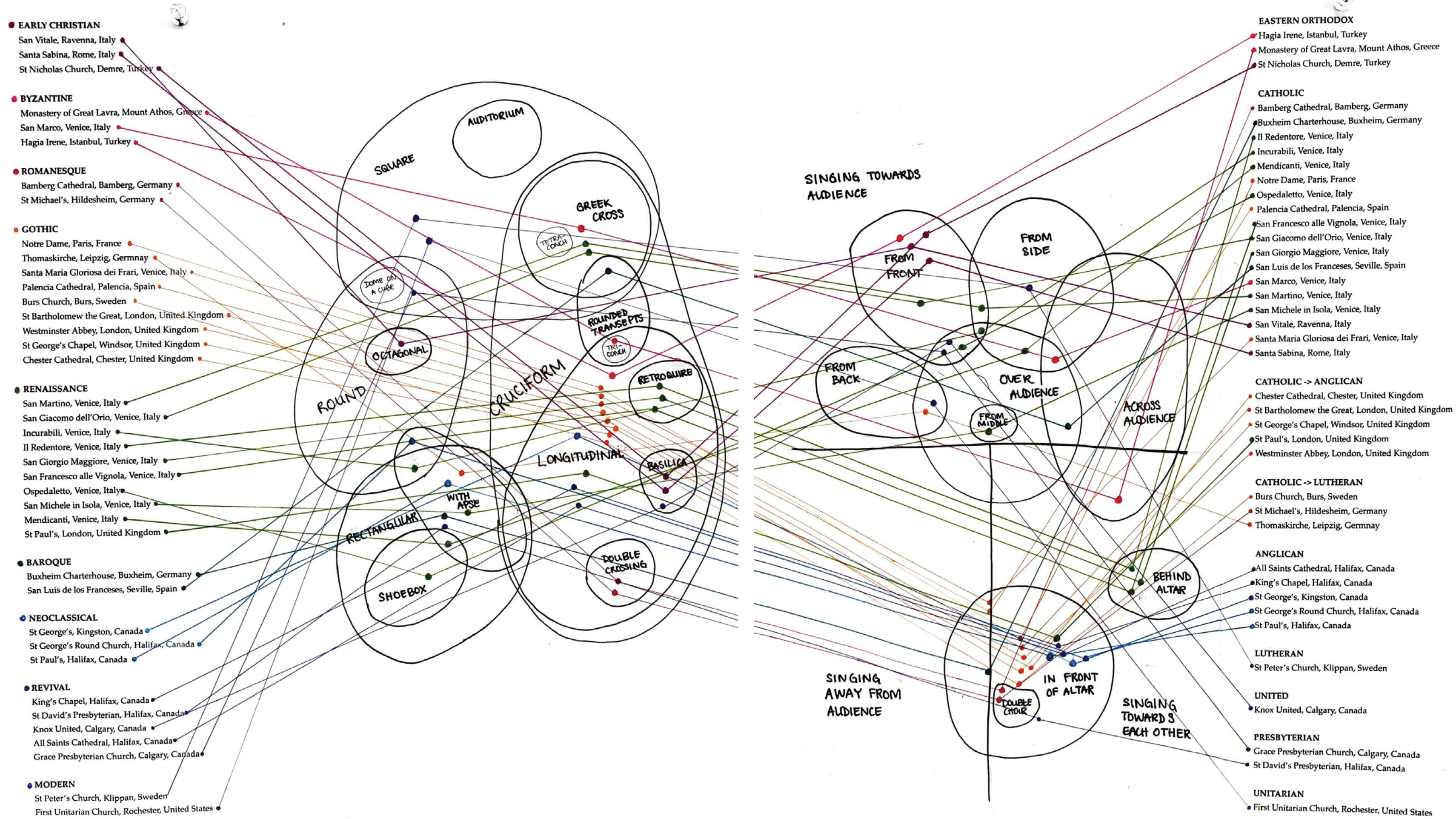
- Suggested recording: Capilla Flamenca, *Adriaen Willaert: Vespro della Beata Vergine.* Ricercar RIC325.
- Recorded in the Kapel Zusters van Sint Vincentius, Gijzegem, Belgium

Reverberant Music

Dove, Jonathan. 1996. “Into Thy Hands.”

- Suggested recording: The Gabrieli Consort, 2012, *A Song of Farewell: Music of Mourning and Consolation*. SIGCD281.
- Recorded in the Lady Chapel of Ely Cathedral, Ely, United Kingdom.

Appendix C: Quire Typology



Appendix D: Early Design Iterations

EXISTING PLAN

Seating:	
Upper floor	170
Lower floor	246
Total	416

Full

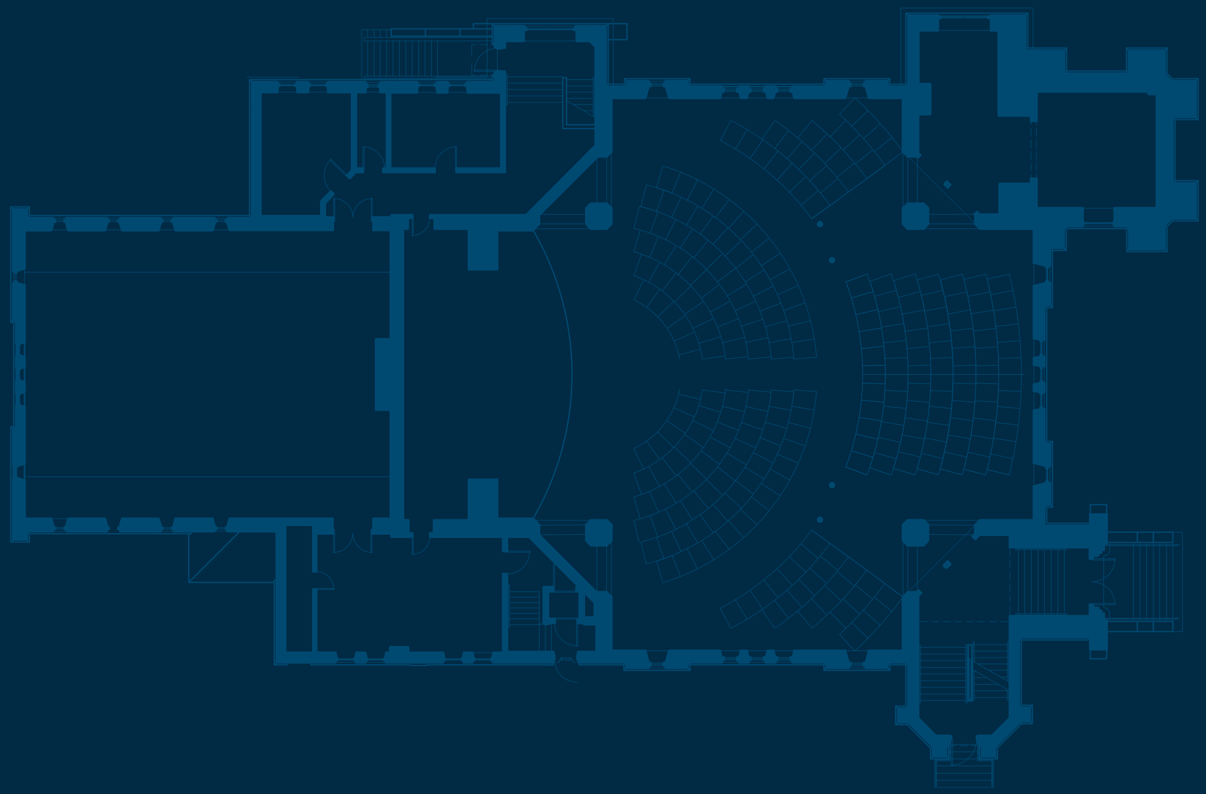
Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	868.41	0.14	117.59
Ceiling	709.97	0.07	49.70
Floor	592.81	0.15	88.09
Occupancy (Full)	252.54	0.59	149.00
TOTAL	2423.726		404.372278

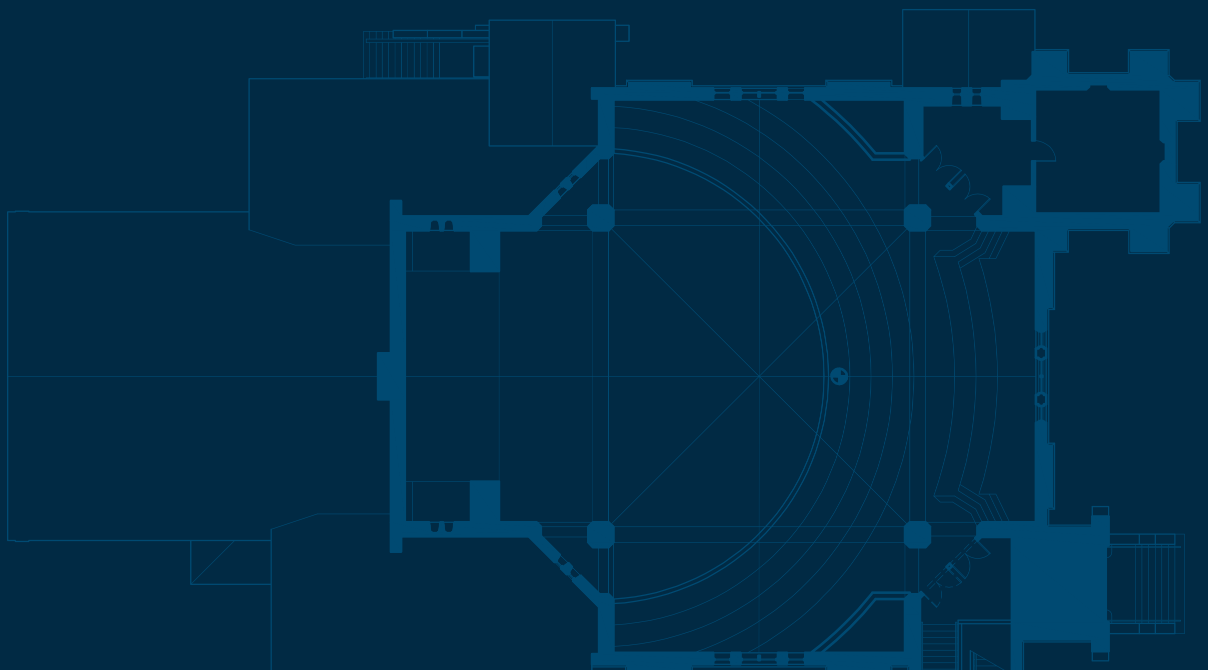
Total Area (m2)	2423.73
Total Absorption (sabins)	404.37
Average absorption coefficient	0.17
Total Volume (m3)	4781.00
Estimate RT60	1.90

Empty

Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	868.41	0.14	117.59
Ceiling	709.97	0.07	49.70
Floor	592.81	0.15	88.09
Occupancy (Empty)	252.54	0.28	70.71
TOTAL	2423.726		326.084878

Total Area (m2)	2423.73
Total Absorption (sabins)	326.08
Average absorption coefficient	0.13
Total Volume (m3)	4781.00
Estimate RT60	2.36





CLOSED IN BALCONY PLAN

Seating:	
Upper floor	170
Lower floor	90
Total	260

Full

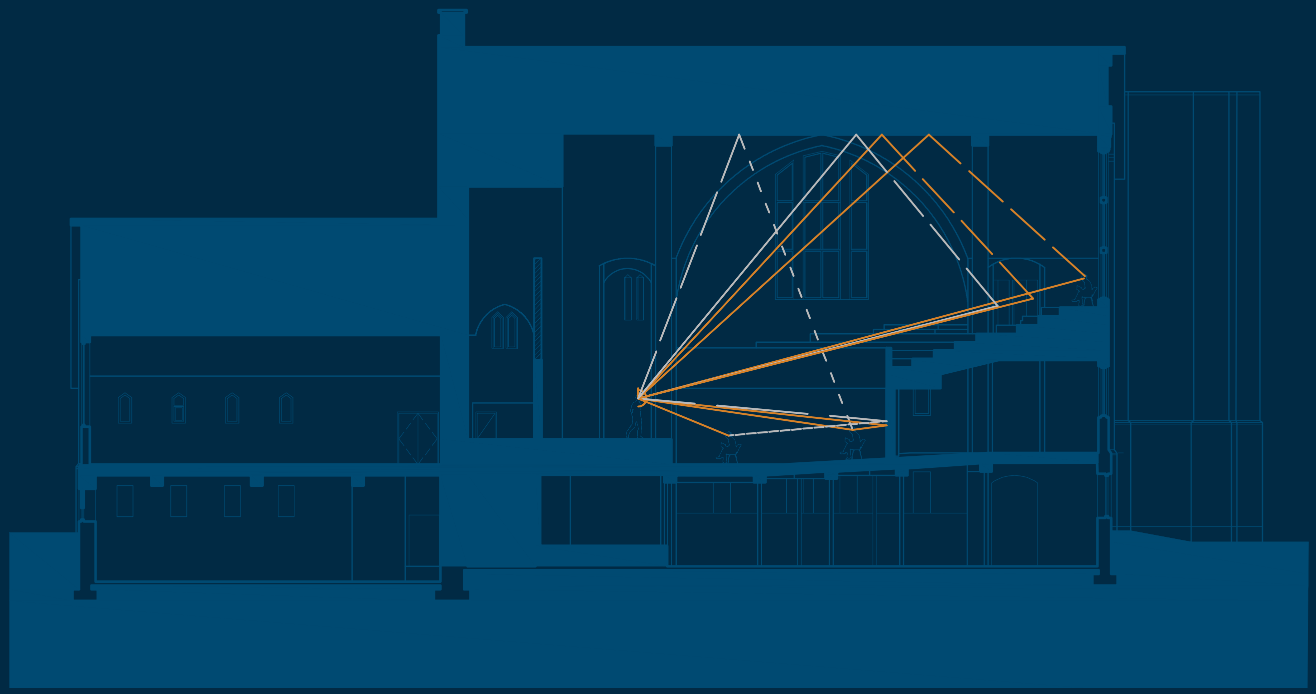
Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	719.15	0.15	107.10
Ceiling	494.97	0.07	34.65
Floor	377.62	0.11	42.95
Occupancy (Full)	156.00	0.59	92.04
TOTAL	1747.735		276.734905

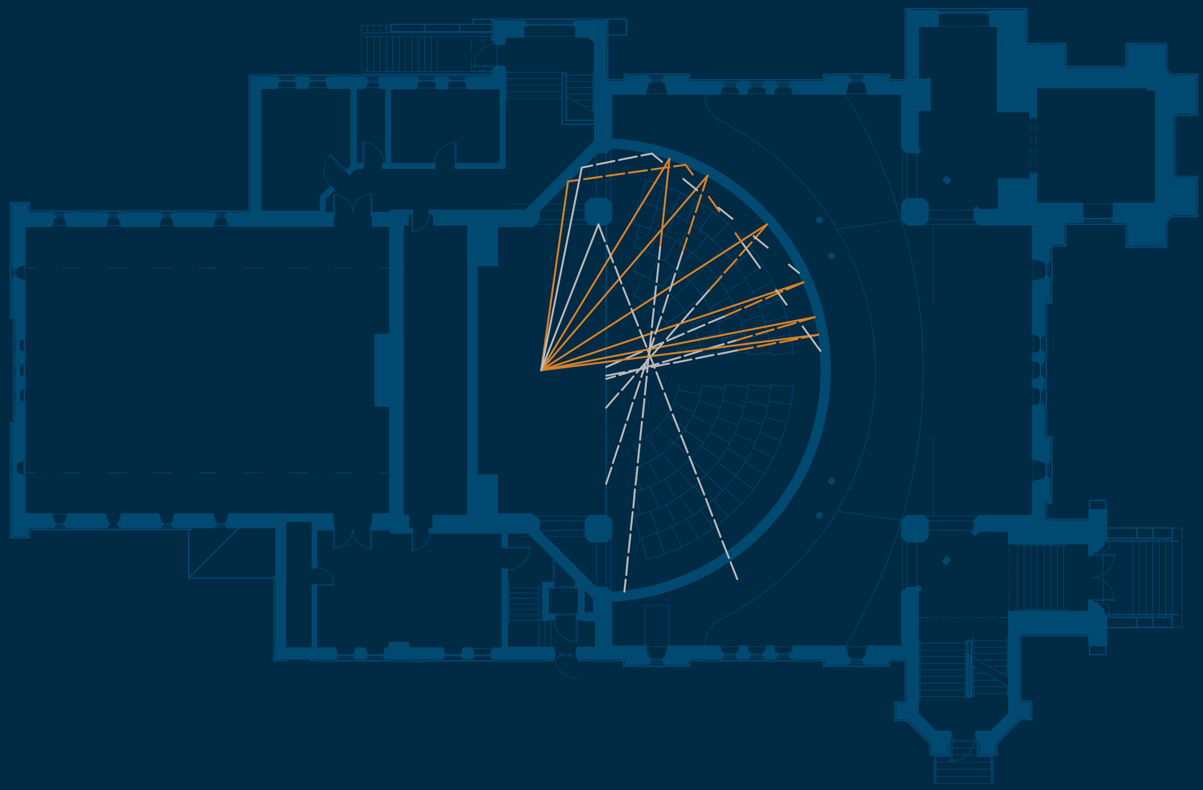
Total Area (m2)	1747.74
Total Absorption (sabins)	276.73
Average absorption coefficient	0.16
Total Volume (m3)	3718.83
Estimate RT60	2.16

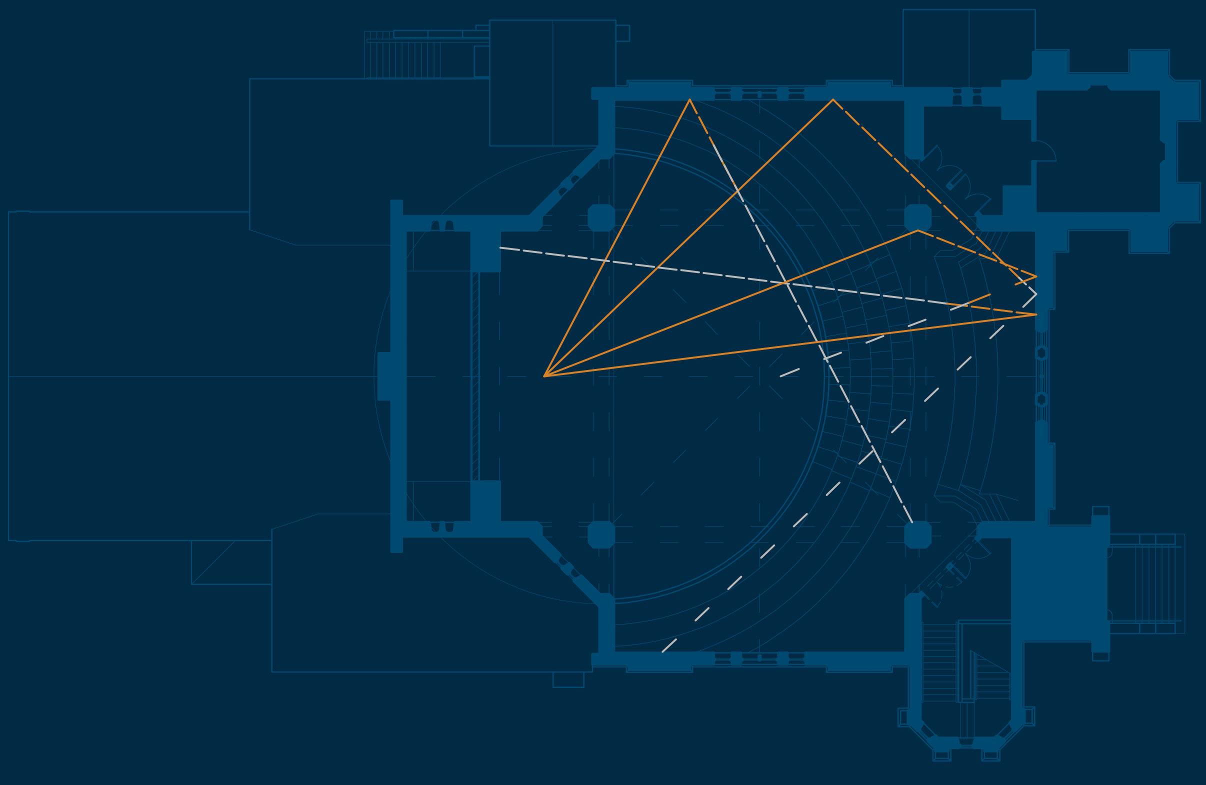
Empty

Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	719.15	0.15	107.10
Ceiling	494.97	0.07	34.65
Floor	377.62	0.11	42.95
Occupancy (Empty)	156.00	0.28	43.68
TOTAL	1747.735		228.374905

Total Area (m2)	1747.74
Total Absorption (sabins)	228.37
Average absorption coefficient	0.13
Total Volume (m3)	3718.83
Estimate RT60	2.62







SHOEBOX PLAN

Seating:	
Upper floor	155
Lower floor	189
Total	344

Full

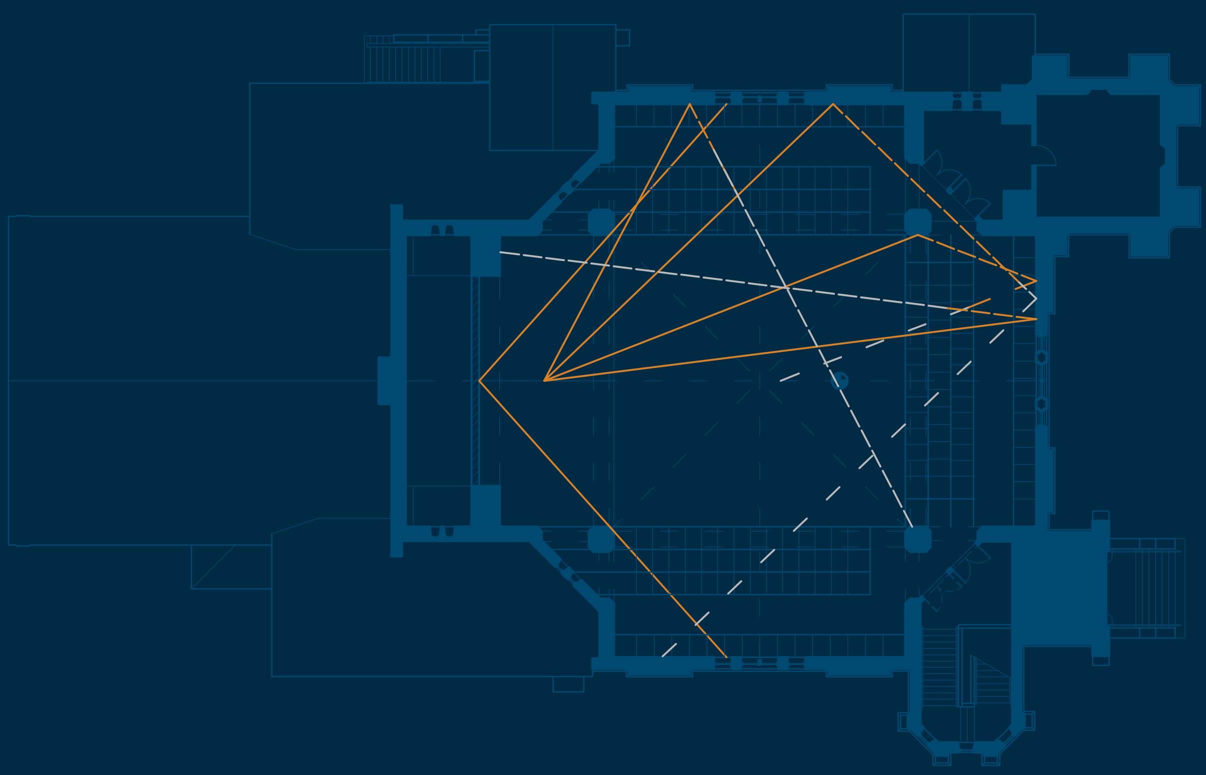
Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	778.93	0.17	133.46
Ceiling	555.06	0.12	63.83
Floor	447.43	0.09	41.61
Occupancy (Full)	205.45	0.59	121.22
TOTAL	1986.87		360.12219

Total Area (m2)	1986.87
Total Absorption (sabins)	360.12
Average absorption coefficient	0.18
Total Volume (m3)	4198.00
Estimate RT60	1.88

Empty

Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	778.93	0.17	133.46
Ceiling	555.06	0.12	63.83
Floor	447.43	0.09	41.61
Occupancy (Empty)	205.45	0.28	57.53
TOTAL	1986.87		296.43269

Total Area (m2)	1986.87
Total Absorption (sabins)	296.43
Average absorption coefficient	0.15
Total Volume (m3)	4198.00
Estimate RT60	2.28



CIRCULAR PLAN

Seating:	
Upper floor	113
Lower floor	131
Total	244

Full

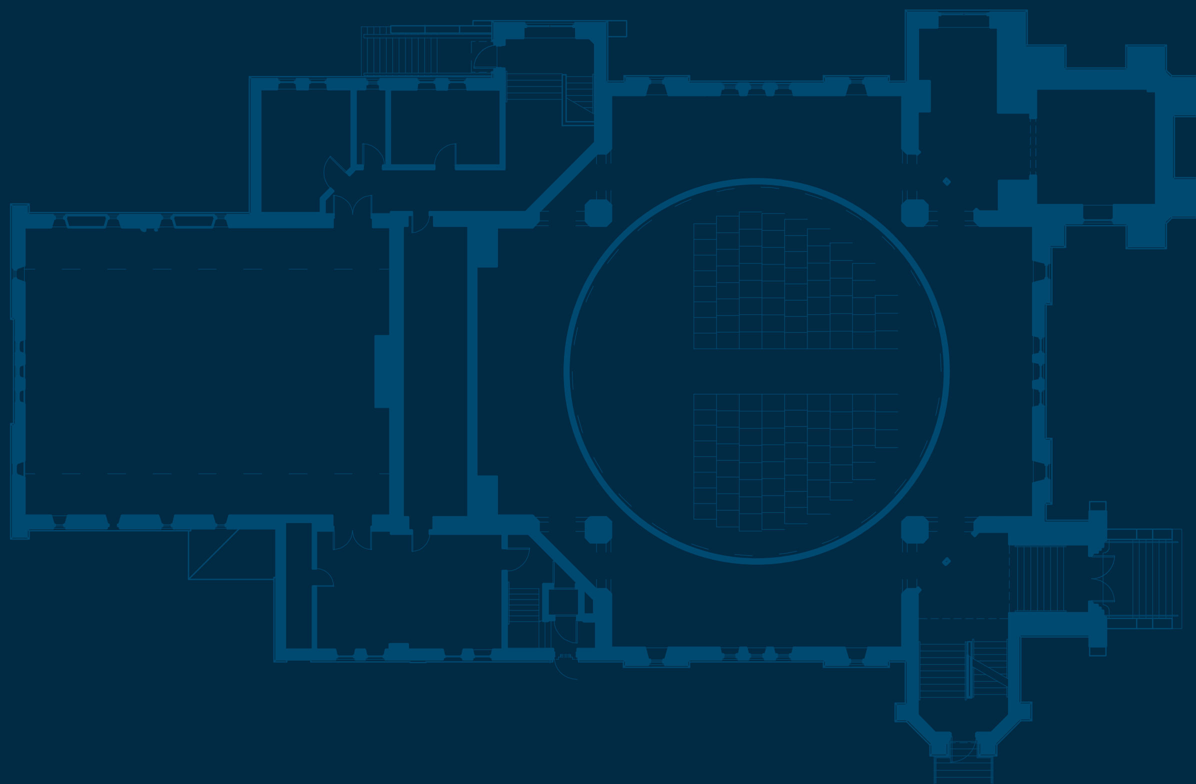
Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	723.83	0.15	105.41
Ceiling	494.97	0.07	34.65
Floor	383.32	0.09	35.65
Occupancy (Full)	156.04	0.59	92.06
TOTAL	1758.156		267.76501

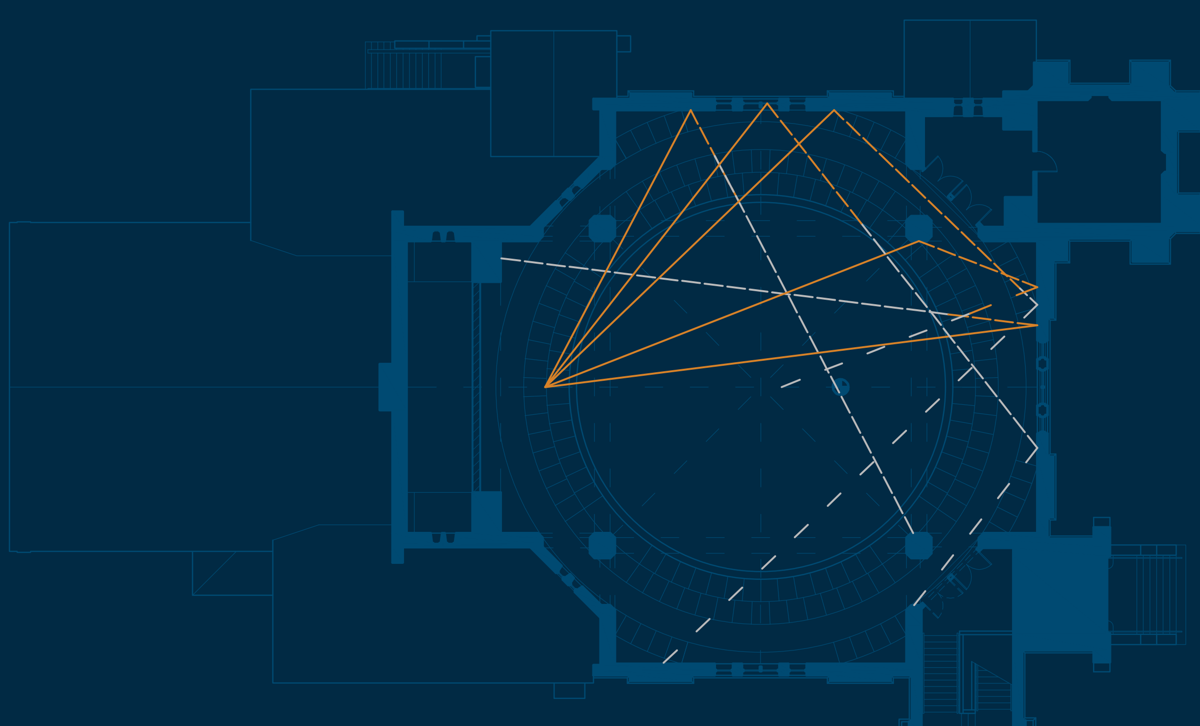
Total Area (m2)	1758.16
Total Absorption (sabins)	267.77
Average absorption coefficient	0.15
Total Volume (m3)	3910.81
Estimate RT60	2.35

Empty

Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	723.83	0.15	105.41
Ceiling	494.97	0.07	34.65
Floor	383.32	0.09	35.65
Occupancy (Empty)	156.04	0.28	43.69
TOTAL	1758.156		219.39385

Total Area (m2)	1758.16
Total Absorption (sabins)	219.39
Average absorption coefficient	0.12
Total Volume (m3)	3910.81
Estimate RT60	2.87





HORSESHOE PLAN

Seating:	
Upper floor	165
Lower floor	119
Total	284

Full

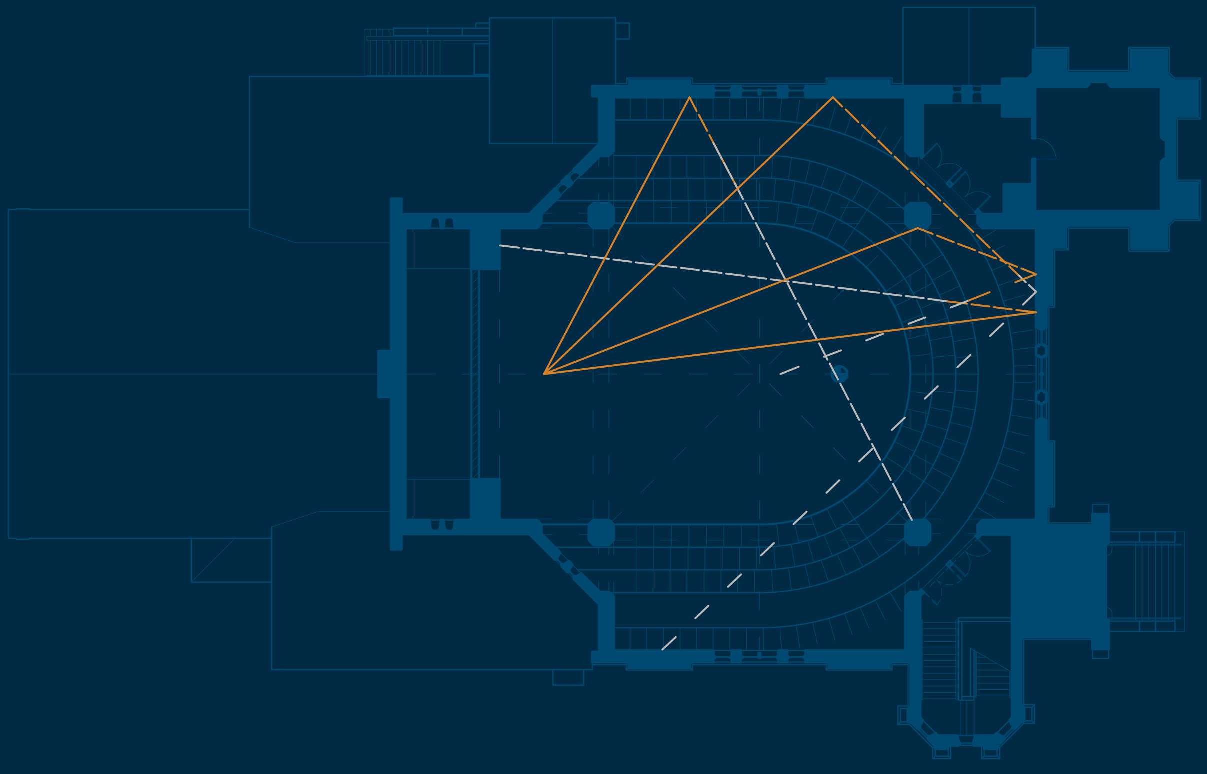
Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	753.12	0.14	108.91
Ceiling	494.97	0.07	34.65
Floor	394.06	0.09	36.65
Occupancy (Full)	169.69	0.59	100.12
TOTAL	1811.837		280.320161

Total Area (m2)	1811.84
Total Absorption (sabins)	280.32
Average absorption coefficient	0.15
Total Volume (m3)	3968.30
Estimate RT60	2.28

Empty

Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	753.12	0.14	108.91
Ceiling	494.97	0.07	34.65
Floor	394.06	0.09	36.65
Occupancy (Empty)	169.69	0.28	47.51
TOTAL	1811.837		227.716261

Total Area (m2)	1811.84
Total Absorption (sabins)	227.72
Average absorption coefficient	0.13
Total Volume (m3)	3968.30
Estimate RT60	2.81



SHOEBOX (but funky) PLAN

Seating:	
Upper floor	159
Lower floor	180
Total	339

Full

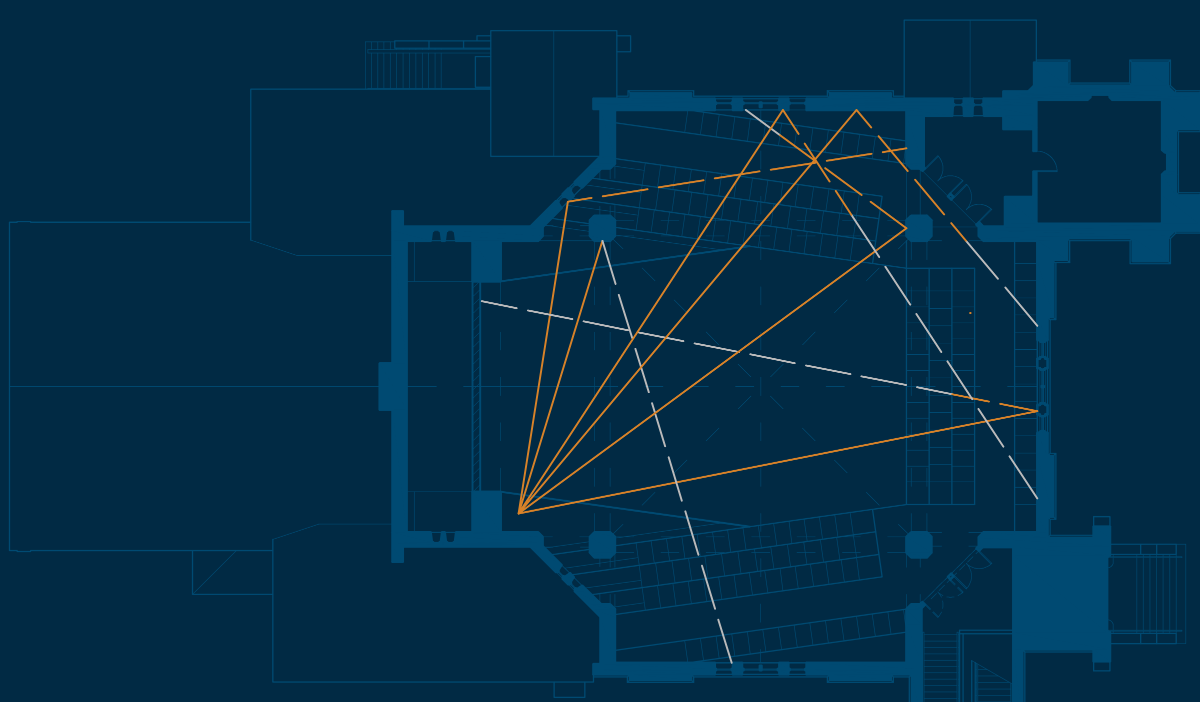
Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	803.78	0.17	137.96
Ceiling	566.05	0.12	67.94
Floor	456.20	0.09	42.43
Occupancy (Full)	198.22	0.59	116.95
TOTAL	2024.25		365.27808

Total Area (m2)	2024.25
Total Absorption (sabins)	365.28
Average absorption coefficient	0.18
Total Volume (m3)	4198.00
Estimate RT60	1.85

Empty

Article	Area (m2)	Average Absorption Coefficient	Absorption (sabins)
Walls	803.78	0.17	137.96
Ceiling	566.05	0.12	67.94
Floor	456.20	0.09	42.43
Occupancy (Empty)	198.22	0.28	55.50
TOTAL	2024.25		303.82988

Total Area (m2)	2024.25
Total Absorption (sabins)	303.83
Average absorption coefficient	0.15
Total Volume (m3)	4198.00
Estimate RT60	2.22



Appendix E: Reverberation Time Calculations

TOTAL SURFACES		Average		Low-frequencies		Mid-frequencies		High-frequencies	
Article	Area (m2)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Walls	919.92	0.087	79.79	0.11	102.55	0.08	75.41	0.06	54.15
Ceiling	729.62	0.077	55.97	0.13	92.61	0.06	44.53	0.04	26.09
Floor	302.49	0.075	22.68	0.09	28.23	0.07	20.67	0.07	21.17
TOTAL	1952.03		158.45		223.38		140.61		101.42

OCCUPANCY - EMPTY			Average		Low frequencies		Mid frequencies		High frequencies	
Occupancy	Material	Area (m2)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Upper seating	Pews - empty	146.97	0.28	41.15	0.18	26.45	0.37	53.64	0.29	42.62
Lower seating	Upholstered seats - empty	148.71	0.50	74.11	0.28	41.64	0.62	91.46	0.59	87.74
TOTAL		295.68		115.26		68.09		145.10		130.36
TOTAL		2247.71		273.71		291.47		285.71		231.78

RT60 CALCULATION		Average	Low frequencies	Mid frequencies	High frequencies
Total Area (m2)	2247.71				
Total Volume (m3)	4259.04				
Total Absorption (sabins)		273.71	291.47	285.71	231.78
Average Coefficient		0.12	0.13	0.13	0.10
Estimate RT60		2.51	2.35	2.40	2.96
Bass Ratio	0.98				

OCCUPANCY - EMPTY			Average		Low frequencies		Mid frequencies		High frequencies	
Occupancy	Material	Area (m2)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Upper seating	Pews - full	146.97	0.59	86.71	0.24	35.27	0.71	103.61	0.81	119.05
Lower seating	Upholstered seats - full	148.71	0.75	111.28	0.48	71.38	0.87	129.38	0.87	129.38
TOTAL		295.68		198.00		106.65		232.99		248.42
TOTAL		2247.71		356.45		330.03		373.60		349.84

RT60 CALCULATION		Average	Low frequencies	Mid frequencies	High frequencies
Total Area (m2)	2247.71				
Total Volume (m3)	4259.04				
Total Absorption (sabins)		356.45	330.03	373.60	349.84
Average Coefficient		0.16	0.15	0.17	0.16
Estimate RT60		1.92	2.08	1.84	1.96
Bass Ratio	1.132				

RT60 and Bass Ratio calculations
Acoustic panels set to reflective, back room closed

TOTAL SURFACES	Area (m2)	Average		Low-frequencies		Mid-frequencies		High-frequencies	
Article		Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Walls	919.92	0.139	127.45	0.13	122.86	0.16	151.79	0.10	91.49
Ceiling	729.62	0.077	55.97	0.13	92.61	0.06	44.53	0.04	26.09
Floor	302.49	0.184	55.64	0.15	43.86	0.18	53.96	0.26	77.67
TOTAL	1952.03		239.06		259.33		250.27		195.25

OCCUPANCY - EMPTY			Average		Low frequencies		Mid frequencies		High frequencies	
Occupancy	Material	Area (m2)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Upper seating	Pews - empty	146.97	0.28	41.15	0.18	26.45	0.37	53.64	0.29	42.62
Lower seating	Upholstered seats - empty	148.71	0.50	74.11	0.28	41.64	0.62	91.46	0.59	87.74
TOTAL		295.68		115.26		68.09		145.10		130.36

TOTAL		2247.71		354.32		327.42		395.37		325.61

RT60 CALCULATION		Average	Low frequencies	Mid frequencies	High frequencies
Total Area (m2)	2247.71				
Total Volume (m3)	4259.04				
Total Absorption (sabins)		354.32	327.42	395.37	325.61
Average Coefficient		0.16	0.15	0.18	0.14
Estimate RT60		1.94	2.09	1.73	2.11
Bass Ratio	1.208				

OCCUPANCY - EMPTY			Average		Low frequencies		Mid frequencies		High frequencies	
Occupancy	Material	Area (m2)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Upper seating	Pews - full	146.97	0.59	86.71	0.24	35.27	0.71	103.61	0.81	119.05
Lower seating	Upholstered seats - full	148.71	0.75	111.28	0.48	71.38	0.87	129.38	0.87	129.38
TOTAL		295.68		198.00		106.65		232.99		248.42

TOTAL		2247.71		437.06		365.98		483.27		443.67

RT60 CALCULATION		Average	Low frequencies	Mid frequencies	High frequencies
Total Area (m2)	2247.71				
Total Volume (m3)	4259.04				
Total Absorption (sabins)		437.06	365.98	483.27	443.67
Average Coefficient		0.19	0.16	0.22	0.20
Estimate RT60		1.57	1.87	1.42	1.55
Bass Ratio	1.32				

RT60 and Bass Ratio calculations
Acoustic panels set to absorptive, back room closed

TOTAL SURFACES		Average		Low-frequencies		Mid-frequencies		High-frequencies	
Article	Area (m2)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Walls	919.92	0.087	79.79	0.11	102.55	0.08	75.41	0.06	54.15
Ceiling	729.62	0.077	55.97	0.13	92.61	0.06	44.53	0.04	26.09
Floor	302.49	0.075	22.68	0.09	28.23	0.07	20.67	0.07	21.17
Extra volume	626.74	0.111	69.75	0.16	100.14	0.08	48.14	0.09	54.10
TOTAL	2578.77		228.20		323.52		188.75		155.52

OCCUPANCY - EMPTY			Average		Low frequencies		Mid frequencies		High frequencies	
Occupancy	Material	Area (m2)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Upper seating	Pews - empty	146.97	0.28	41.15	0.18	26.45	0.37	53.64	0.29	42.62
Lower seating	Upholstered seats - empty	148.71	0.50	74.11	0.28	41.64	0.62	91.46	0.59	87.74
TOTAL		295.68		115.26		68.09		145.10		130.36
TOTAL		2874.45		343.46		391.62		333.85		285.88

RT60 CALCULATION		Average	Low frequencies	Mid frequencies	High frequencies
Total Area (m2)	2874.45				
Total Volume (m3)	5141.74				
Total Absorption (sabins)		343.46	391.62	333.85	285.88
Average Coefficient		0.12	0.14	0.12	0.10
Estimate RT60		2.41	2.11	2.48	2.90
Bass Ratio	0.853				

OCCUPANCY - EMPTY			Average		Low frequencies		Mid frequencies		High frequencies	
Occupancy	Material	Area (m2)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)	Absorption Coefficient	Absorption (sabins)
Upper seating	Pews - full	146.97	0.59	86.71	0.24	35.27	0.71	103.61	0.81	119.05
Lower seating	Upholstered seats - full	148.71	0.75	111.28	0.48	71.38	0.87	129.38	0.87	129.38
TOTAL		295.68		198.00		106.65		232.99		248.42
TOTAL		2874.45		426.20		430.18		421.74		403.95

RT60 CALCULATION		Average	Low frequencies	Mid frequencies	High frequencies
Total Area (m2)	2874.45				
Total Volume (m3)	5141.74				
Total Absorption (sabins)		426.20	430.18	421.74	403.95
Average Coefficient		0.15	0.15	0.15	0.14
Estimate RT60		1.94	1.92	1.96	2.05
Bass Ratio	0.98				

RT60 and Bass Ratio calculations
Acoustic panels set to reflective, back room open

	FREQUENCY (Hz)							
Material	**125**	**250**	**500**	**1000**	**2000**	**4000**	**AVERAGE**	**Source**
Plaster on concrete	0.01	0.02	0.02	0.03	0.04	0.05	0.028	Egan 1988, 52
Brick (unglazed)	0.02	0.02	0.03	0.04	0.05	0.07	0.038	Egan 1988, 52
Plaster on lath	0.14	0.10	0.06	0.05	0.04	0.03	0.070	Egan 1988, 52
Brass	0.05	0.10	0.10	0.10	0.07	0.02	0.073	Egan 1988, 52
Wood flooring	0.15	0.11	0.10	0.07	0.06	0.07	0.093	Egan 1988, 52
Wood panels (1") with airspace	0.19	0.14	0.09	0.06	0.06	0.05	0.098	Egan 1988, 52
Tongue and groove wood	0.24	0.19	0.14	0.08	0.13	0.10	0.15	JCW Acoustic Supplies n.d.
Wood panels (1/4") with airspace	0.42	0.21	0.10	0.08	0.06	0.06	0.155	Egan 1988, 52
Glass (ordinary)	0.35	0.25	0.18	0.12	0.07	0.04	0.168	Egan 1988, 52
Wood pews, occupied	0.10	0.26	0.39	0.34	0.29	0.29	0.280	Carvalho & Pino 2012, 6
Organ pipes	0.35	0.35	0.20	0.20	0.30	0.35	0.292	Boren 2021, 5
Carpet on concrete	0.02	0.06	0.14	0.37	0.60	0.65	0.307	Egan 1988, 52
Fabric upholstered seats, unoccupied	0.19	0.37	0.56	0.67	0.61	0.59	0.498	Egan 1988, 53
Wood pews, unoccupied	0.17	0.31	0.63	0.78	0.83	0.81	0.590	Carvalho & Pino 2012, 6
Acoustic panels	0.09	0.56	0.99	1.02	0.76	0.52	0.657	Kinetics Noise Control 2023, 2
Fabric upholstered seats, occupied	0.39	0.57	0.80	0.94	0.92	0.87	0.748	Egan 1988, 53

Absorption coefficients used

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