Science in the Church:

the Sacred Spaces of Sonorous Experiment and the Formation of Modern Acoustics[1]

Historians of science have long stressed the spatial contingency of knowledge of nature. While "modern" science has been marked by the formalization of highly disciplined sites of inquiry, notably observatories and laboratories, past scientific practitioners have mobilized a diverse range of locations, including kitchens, workshops, domestic homes, and ships, in which to isolate natural phenomena and submit them to precise observation and accurate measurement.[i] There was one phenomenon, however, in which this question of locality was especially important to how it was experienced: sound. Given that the size, space, furnishings, and volume of a room determines the character of a communicated sound, the places in which natural philosophers have investigated sonorous phenomena have been crucial to the formation of acoustic knowledge. This involved work in a broad array of settings, from caves and mountain tops, to theatres and debating chambers, but it was the church that provided some of the most important sonorous encounters contributing towards scientific understandings of sound. This article explores this central role of ecclesiastical space in the cultivation of acoustic science and argues that, because of their architectural diversity, unrivalled physical extent, and the moral urgency of communicating sound within these places of spiritual instruction, churches and cathedrals offered unique insights into how sound behaved and the material determinants of its character. Significantly, it was during the expansive church-building programs and socio-political upheavals experienced in nineteenth-

[1] This work was made possible thanks to generous funding from the Leverhulme Trust as part of the Early Career project, The State of Science: governing knowledge of nature in Victorian Britain. We would like to thank colleagues at the University of Leeds' School of Philosophy, Religion and History of Science, as well as at the Bartlett School of Sustainable Construction, University College London, and NYU's Music Department (Faculty of Arts and Sciences). Particular thanks are due to David Trippett, Graeme Gooday, D'Maris Coffman, and Judy Stephenson for all their support. This text also benefited from productive discussions at one of the sessions of the "Analyse des pratiques musicales"'reading group (STMS Lab, CNRS / IRCAM).

century France and Britain that the church would assume its most prominent role within the production of acoustic knowledge.

Sound has always had a prominent part in Christian worship, but it was the Western European development of larger Gothic churches and cathedrals, particularly from the late-twelfth and early thirteenth centuries, characterized by increasingly elevated vaulted ceilings, immense internal volume, and broken-up internal arrangements of lofty piers, ribs, and buttresses, that transformed the soundscapes of medieval ecclesiastical space. These Gothic structures produced unusual effects in terms of echo and reverberation, making obvious places in which early modern natural philosophers could cultivate new understandings of sound's properties.[ii] In his *Sylva Sylvarum* (1626), for example, Francis Bacon (1561-1626) invoked Gloucester Cathedral's fourteenth-century "whispering gallery" to illustrate the phenomenon of echo, describing how a weak voice "slideth along the Wall" to become audible at the far end of the hall.[iii] Likewise, Marin Mersenne's (1588-1648) *Harmonie universelle* (1636-7) included ecclesiastical buildings as places where the phenomena of echo and resonance could be experienced and related to variations in architectural form. With their smooth walls, flat ceilings, and wooden paneling, Classical Roman and Greek temples provided contrasting sonorous effects to medieval Gothic churches, full of lavish ornament, ribs, vaulting, and arches. As Mersenne put it, while in "ordinary churches … the vault and other parts either of the pulpit or of the walls reflect the voice below," Classical temples and churches produced a more upward projection of sound, although he could not account for these differences.[iv]

By the nineteenth century, Europe's churches were far more varied in architectural style, including Romanesque, Baroque, and Neoclassical constructions, which presented alternate sonorous effects and contributed to a growing awareness of how a building's form determined its acoustic qualities.[v] These sites made ideal experimental locations in which scientific practitioners could isolate natural phenomena, perform sonorous experiments, and

develop inductive frameworks for understanding sound. As European scientific culture became increasingly spatially organized, particularly through the rise of disciplined observatories and physical laboratories tasked primarily with the performance of precise measurement and production of standardizing units, churches remained leading venues of knowledge making. In particular, when it came to sound, the church's epistemological value endured. Yet this was not a location of disciplined empirical enquiry or controlled experimental practice, but a space in which natural phenomena could be experienced.

The question then, is what sort of epistemological sites did nineteenth-century churches constitute? The appropriateness of past venues of scientific activity has often been contested but, at a basic level, such a site must ideally be one in which a specific natural phenomenon can be scrutinized, with disturbing external variables minimalized. Yet, as historians of science have demonstrated, these also had to be places of social organization and involved careful demarcation as places in which reliable truth claims about nature could be produced.[vi] In early modern Europe, for instance, it was the home, specifically the kitchen, that was the predominant place of philosophical investigation.[vii] These private sites were the location of complex physical and social regimes: here, natural philosophers looking to manufacture knowledge claims could manage who witnessed their experiments and how they were reported to wider audiences. As Steven Shapin has demonstrated, such validation of scientific work has historically been marked by visual regimes of social and experimental organization.[viii]

When considering the church as a site of scientific activity, however, these physical and social regimes for ordering testimony and building scientific consensus become problematic. Undoubtedly, these buildings possessed unique sonorous qualities: the biggest medieval churches constituted Europe's largest spaces of contained air in which the movement of sound could be observed. These voluminous buildings produced diverse

sonorous phenomena, including of echo and reverberation, that were unrivalled in scale to comparative natural and human-built locations: this was an architectural network of contrasting experimental sites that were subject to variations in material structure, temperature, humidity, and congregation size. During the eighteenth and early nineteenth century, theatres, debating chambers, and concert halls were all places in which sound could be examined. Yet none of these matched the dimensions of Europe's great cathedrals, nor did they provide comparable moral urgency to understand how best to accurately communicate speech, given that churches were sites of spiritual instruction.

This social role meant that, although offering rich resources with which to fashion new acoustic knowledge, churches were also profoundly difficult spaces to discipline, both physically and socially. Unlike the visual organization that Shapin identified as crucial to experimental work, the church was a space that defied such ordering regimes. The audiences of these places of worship were socially diverse, transcending class boundaries and established political hierarchies, meaning that there was no single acoustic experience of the church. It was not just that the church was a public setting, but that the physical nature of sound itself defied the organization that could be applied to a visual experiment. Whereas an experimentalist could manage who witnessed an electrical or chemical demonstration within a lecture theater, sound's ability to permeate space ensured that almost anyone with a functioning ear could hear the sonorous phenomena that natural philosophers discussed. At once, this made observations in churches both epistemologically troubling and also immensely productive. Sonorous knowledge was, because of its spatial qualities and cultural contexts, knowable to diverse social audiences, but was also contestable by a broad range of critics of varying scientific credentials. As our paper demonstrates, these not only included mathematicians and experimentalists, but architects, clergymen, politicians, theologians, historians, and organ builders. Concomitantly, knowledge produced in churches often carried

religious, social, and political implications: as places of worship, these could never just be passive venues of physical investigation, especially amid the post-revolutionary social unrest of the nineteenth century. In recovering the centrality of the church as an experimental site, our article delivers a cultural history of acoustics, emphasizing the practices and contexts of scientific inquiry.

In recent years, historians of science and musicologists have emphasized the connections between musical and scientific cultures, forging new understandings over the production of past sonorous knowledge.[ix] While these endeavors have illustrated the skills, institutions, actors, and material networks at play in historic scientific activity, the epistemological position of the church has been ignored. Previous historiographical attention has, instead, focused on secular sites, notably workshops, museums, music venues, and scientific institutions.[x] In contrast, our article analyses the religious spaces of sonorous investigation. Importantly, to unpack the different ways in which varying congregational traditions and ritualistic priorities shaped varying bodies of knowledge, we compare the differing relationship between ecclesiastic space and sound encountered in France and Britain during the nineteenth century. Both countries shared a common Gothic architectural inheritance and, from the 1830s, French and British scholars were eager to fashion more empirical understandings of these religious buildings. While they drew on architecture from across Europe, it was Britain and France's churches and Cathedrals that were central to the formation of acoustic knowledge. These were two of Europe's first industrial nations and places of growing social unrest, but they were also home to dramatically different religious cultures. The established Church of England and series of non-conforming dissenter churches marked a broad Protestant tradition throughout the British Isles. In contrast, Roman Catholicism remained dominant in France, especially amid the state-sponsored restoration program that followed the revolutionary de-Christianization of the 1790s. These alternate

religious contexts had epistemological implications. Within Protestantism, the Reformation's emphasis on speech and the articulation of sermons from pulpits shaped examinations of sound centered on the communication of the spoken word. But the importance of chant and polyphonic music in Catholic forms of worship involved contrasting sonorous priorities: diverse religious cultures informed differing intellectual frameworks, with protagonists placing varying degrees of emphasis on experimental, mathematical, and archeological knowledge.[xi]

Our article offers a comparative analysis of empirical inquiry in French and British places of worship, examining how varying Protestant and Catholic liturgical commitments shaped varying bodies of knowledge. Our selection of France and Britain is intended to emphasize the importance of historical contingency in past sonorous knowledge production: differing historic experiences shaped alternate acoustic priorities. For Britain, with the rise of industrial towns and cities, the great challenge was to build new churches with effective acoustics, while for France, whose churches had been damaged through the revolutionary unrest of the 1790s, the challenge was one of restoring historic soundscapes, including the construction of new organs. Of course, this is not to reductively assume that French church builders were not interested architectural acoustics or that there was no innovation among Britain's organ builders, but our comparative analysis highlights broad variations in sonorous commitments. We begin, chronologically, with Britain, where there was strong emphasis on experimentation as a solution to the architectural challenge of building churches of good audibility. During the 1820s and 1830s there was a growing concern with ensuring that British sermonizers could be heard and congregations efficiently instructed. As we will then show, this was quite different to French approaches to managing sound in ecclesiastical spaces. In France, there was a greater emphasis on recovering the lost historic soundscapes of medieval worship, notably in terms of musical culture and chant. However, there was also much

innovation, especially in terms of the design and construction of organs, which not only involved highly skilled manufacturing practices, but scientific understandings of how instrumental sounds moved through a church. Finally, in part three, we argue that, from the late-nineteenth century, scientific practitioners gradually mobilized the knowledge and resources of church-based acoustics within the development of laboratory culture. Here, our analytical focus shifts, in part, from that of ecclesiastical space, to that of ecclesiastical artefact. We will conclude by considering how this study problematizes Emily Thompson's account of the rise of early twentieth-century electroacoustic technologies and laboratory culture as a fundamentally secularizing experience.[xii] As much as Euro-American soundscapes underwent a transformation during this period, ecclesiastical space remained central to the formation of sonorous knowledge.

1. British Architects, Churches, and Communicating Speech

From the early nineteenth century, there was increasing socio-political urgency for understanding how sound behaved inside religious buildings. The experience of the French Revolution of 1789, combined with rapid population growth, urbanization, and industrialization on both sides of the Channel, encouraged religious and political elites to re-evaluate the significance of the church as a site of social control and moral instruction. These fears of social unrest initiated the construction of new, and restoration of old, places of worship. Since the mid-eighteenth century, the redistribution of inhabitants from the countryside to Britain's industrial towns and cities, created an imbalance in church accommodation which, many felt, would ferment revolution. While rural Britain was richly provisioned with parish churches, towns like Sheffield and Manchester struggled to cope. The Church of England had proved woefully incapable of keeping up with this escalating urban demand. Alarmed, Parliament passed the Church Building Act of 1818, providing £1million

for state-subsidized churches and establishing a Church Building Commission to oversee the project. Between 1818 and 1856, the British government funded 612 new churches, and by the 1860s there was, on average, a new Anglican church consecrated every three to four days.[xiii] Yet to ensure that these buildings delivered their intended spiritual guidance, it was crucial they be places of good sonorous communication and it was the audibility of the sermon that was the dominating acoustic priority. Initially there was a preference for neoclassical, but these structures were expensive, requiring vast stone-column porticoes; the commission therefore encouraged architects to adopt a Gothic style, employing brick.[xiv] However, it soon became clear that there was a national shortage of experience in Gothic-church design, with Britain's architects more accustomed to constructing Neoclassical temples in which it was easy to secure an even distribution of sound. Compared with the open interiors, smooth walls, and flat ceilings of Roman or Greek style churches, it seemed to contemporaries that sound behaved differently inside Gothic structures. Unsurprisingly, throughout the 1820s, architects struggled to deliver good acoustics. At Ashton-Under-Lyne, for instance, the Bishop of Chester complained of excessive reverberation, while many clergymen were forced to continually reposition the pulpits of their brand-new churches to ascertain a place from which their congregations could clearly hear sermons.[xv] These architectural failings, resulting directly from Britain's new church-building programme, stimulated calls for the formation of new understandings of the relationship between physical enclosed space and sound's behaviour, specifically in terms of the communication of speech.

Since the eighteenth century, architects had paid increasing attention to sound's behaviour in theatres, but there was no authoritative guide to securing good hearing in buildings of more complex shapes and extensive internal volumes. However, the 1820s and 1830s was a moment of intense scientific interest in sound following the recent translation of Ernst Chladni's (1756-1827) *Die Akustik*, first published in 1802. Chladni's treatise included

several prominent ecclesiastical buildings where unique sonorous phenomena could be experienced. Describing "whispering galleries", for example, Chladni cited Gloucester Cathedral, along with more recent constructions, notably the even propagation of sound around the dome of Wren's St Paul's Cathedral and a similar effect in Sicily's Romanesque Agrigento Cathedral.[xvi] Chladni explained that such phenomena, especially when musical, could produce intensely religious encounters. He had himself observed an

> effect of music at Ludwigslust in the church of the court of the Duke of Mecklenburg-Schwerin. The church has a single nave; all the way at the end, where the altar is found, there is a tableau that represents the appearance of the angels that announced the birth of Jesus Christ to the shepherds. Between the boards on top that form the clouds is seated an orchestra that … is not seen; all the sound is poured out from the top and only reaches the public by reverberations from the ceiling. The sound is beautiful and distinct, and before knowing of the construction of the Church, it is difficult to guess where it comes from.[xvii]

Chaldni's point here was not just that the music he heard was beautiful, but that the concealment of its place of origin created a sense of mystery, helping to transform the church into a place of profound spiritual wonder. This was, to a large degree, what made religious architecture so acoustically significant for natural philosophers: here, a good knowledge of the relationship between a building's physical form and the sonorous effects this produced could enhance a church's ability to evoke religious sentiment and feeling. Unlike in secular buildings, places of worship were sites in which sound was to be mobilized to deliver transcendental experiences.

Chladni's architectural examples of sonorous phenomena proved influential with leading nineteenth-century acoustic authorities, encouraging them to draw on such religious spaces in their own accounts of sound. In 1830, notably, John Herschel (1792-1871) drew on Chladni to publish what was to become the definitive English work on acoustics for almost

half a century, appearing within *Encyclopaedia Metropolitana*. Herschel was particularly concerned with sound's propagation through air, detailing the acoustics of Gloucester and St Paul's cathedrals, as well as St Alban's Abbey Church—where a watch could be heard from one end to the other—, and Shipley Church in Sussex—which could repeat up to twenty-one syllables. Attesting to the centrality of speech communication in Britain's culture, Herschel was particularly attentive to the challenge that reverberation posed to sermon's intelligibility. Just like in Chladni's influential treatise, religious buildings were not coincidental to Herschel's study of sound, but constituted the overwhelming majority of locations cited for their acoustic qualities.

It was not just that the latest scientific treatises on sound were grounded in experiences of ecclesiastic space, but that such knowledge promised a solution for Britain's struggling church builders. This became apparent during the 1830s when the House of Commons sought to improve the acoustics of its debating chamber. Conflating sermonizing and political speechifying, MPs hoped to mobilize architects' recent experiences of church building within the fashioning of an improved political space, launching a select committee in 1831 to interview the nation's leading architectural authorities over the communication of speech. With the Commons housed in the Gothic St Stephen's Chapel, the committee was particularly interested in what architects had to say about sound's behavior within ecclesiastical buildings. As much as this consultation illustrated the deficiencies of acoustic knowledge among Britain's architects, it also revealed that they had, in fact, cultivated considerable learning over what sort of room ensured good hearing and had engaged with leading works of natural philosophy. The evidence of the committee's first witness, Benjamin Wyatt, demonstrated his acquaintance with philosophical understandings of sound propagation as a vibratory impulse through a fluid-like medium of particles.[xviii] When Parliament established a second committee, in 1833, architect James Savage (1779-1852) employed a similar scientific

manner in his proposals to rebuild the House of Commons as a Neoclassical amphitheater. A leading London church builder, Savage asserted that if architects wanted their churches to be places of audible moral instruction, they should follow Chladni's principles that "a room will be favourable to sound, 1st, when it is well arranged to facilitate the natural progress of sound; 2dly, when the intensity of the sound is augmented by the resonance of other bodies, or by suitable reflections."[xix]

Savage's activities illustrate not only how the conception of sound's propagation informed architects in building new church interiors, but also how the business of constructing new ecclesiastical architecture itself stimulated the production of new knowledge of sound. Citing his Gothic masterpiece of St Luke's Church in Chelsea, he observed that it was "constantly found in churches that the clergyman is heard better from the altar than from the pulpit or reading desk. This is doubtless from the wall at the back acting as a reverberator, and the side walls as conductors."[xx] The problem with ecclesiastical Gothic buildings was that their large internal projections broke up the movement of sound, reflecting it in different directions. Savage observed that deep recesses in walls and ceilings swallowed up sound, such as in cruciform churches, of which Hackney Church was a good example. As much as Savage drew on Chladni's philosophical treatise, the practical experience of sound's movement through church architecture informed his understanding of sonorous communication. Subsequent committee interviews uncovered much disagreement among architects over how to deliver effective hearing and speaking, but there was a consensus that Britain's recent church-building program had provided valuable insights over this matter. Savage's evidence was not only revealing of how he understood sound propagation, but demonstrated an eagerness to portray himself as an architect of scientific principles. Transferring Chladni's acoustic theory to practical construction was difficult but, more importantly, architects were

not passively consulting scientific accounts of sound, but extending them: church building was also knowledge building.

Despite this, the consensus at Westminster was that architects failed to understand sound's behaviour in buildings. When MPs returned to the question of the acoustics of the House of Commons, following the destruction of the Palace of Westminster in a fire in 1834, they instead consulted an Edinburgh chemist, David Boswell Reid (1805-1863). Commissioned to produce new acoustic knowledge to guide the construction of the replacement debating chambers for the Commons and Lords, Reid orchestrated an industrious series of experiments, including several arrangements with the seating, walls, and ceiling of a temporary chamber erected for the Commons. Unlike Savage or Wyatt, Reid's experience as a chemist ensured a very different approach to those that practicing architects pursued. It was his driving conviction that the only way to secure good acoustics was through a powerful system of ventilation, to effectively manage the chemical composition of the building's air and achieve a homogeneous atmosphere through which speech could effectively travel.[xxi] As much as this was a political architectural project, the new palace was, with its Gothic style and lavish medieval ornamentation, an essentially ecclesiastical building, adorned with sculptures of saints and sovereigns, while the Commons' chamber maintained the cross-benched structure of St Stephen's Chapel with prayers read before each day's proceedings.[xxii] Significantly, Reid was well acquainted with the acoustic properties of Scotland's Presbyterian chapels and believed that sonorous communication was contingent on a building's atmosphere: churches were, he claimed, difficult to hear in because of the build-up of carbonic acid from a congregation's respiration, as well as drafts and temperature variations. The atmosphere of a church was heterogeneous, which made it difficult for sound waves to travel from a preacher to his audience and for congregations to remain focused.[xxiii] Given the centrality of sermons within Scottish religion, it is little wonder that Reid found

these acoustic failings deeply troubling. After all, what was the point of practicing a reformed religion in which local languages replaced Latin, if a minister's voice could not be heard? At stake here, was the entire basis of Protestantism and, specifically, Scotland's Calvinist tradition. More than this, Reid's church-based observations directly informed his acoustic experiments within the nation's foremost political space.

The urgency to secure good sonorous communication within public buildings not only shaped the acoustics of Britain's two political centers, but also transformed the nation's ecclesiastical soundscapes. The acoustic failings of British architects sustained considerable experimental activity in churches across Britain. The most celebrated example of this took place at Attercliffe, near Sheffield. Having received a grant from the Church Building Commission to erect a new church, Rev John Blackburn had been disappointed with the completed building's acoustics: the rectangular interior with an elliptical recess, 56ft-high nave, and vaulted roof produced a confused and indistinct sound.[xxiv] To resolve this, Blackburn, a graduate of St John's College Cambridge, adopted an experimental approach, repositioning his pulpit and recording how well his congregation could hear him.[xxv] These trials failed to correct the problem, but in 1828 Blackburn published an account of a new sounding-board that he had inserted into the church, in the Royal Society's *Philosophical Transactions*. **(Figure 1)** A local artisan had built a wooden structure in the form of a parabola, producing a concave surface, which inclined forward at an angle of ten to fifteen degrees over the pulpit, dramatically increasing the volume of a preacher's voice.[xxvi] This sounding-board was designed as a groined canopy, ornamentally decorated with crockets and leaves, with a curtain suspended down either side to prevent sound from escaping beneath the reflector.[xxvii] Sermons were thus thrown out over the congregation. Clearly, Blackburn asserted, "unless the sounding board be constructed with mathematical nicety and placed with mathematical precision, much of the effect will be lost." He concluded that architects should

take note of the reflector's shape in church design and give the east end of their buildings the form of a parabolic concave, placing their pulpits in the focus of this form.[xxviii] This apparatus certainly impressed William Farish (1759-1837), Jacksonian Professor of Natural Philosophy at Cambridge, and vicar of St Giles's church. To meet Cambridge's growing population, Farish remodeled the medieval Gothic edifice, increasing its seating from 100 to 600, but incurring a reduction in acoustic quality as a result. In May 1829, he wrote to Blackburn, requesting "the artist" responsible for Attercliffe's sounding-board be sent to Cambridge to erect a similar contrivance in St Giles's. Farish had already visited Attercliffe to acquire "experimental and practical proof." By February 1830, he was pleased to report that the power of a preacher's voice within his own church had been strengthened beyond all expectation and that sermons could now be heard clearly in all parts of the building.[xxix]

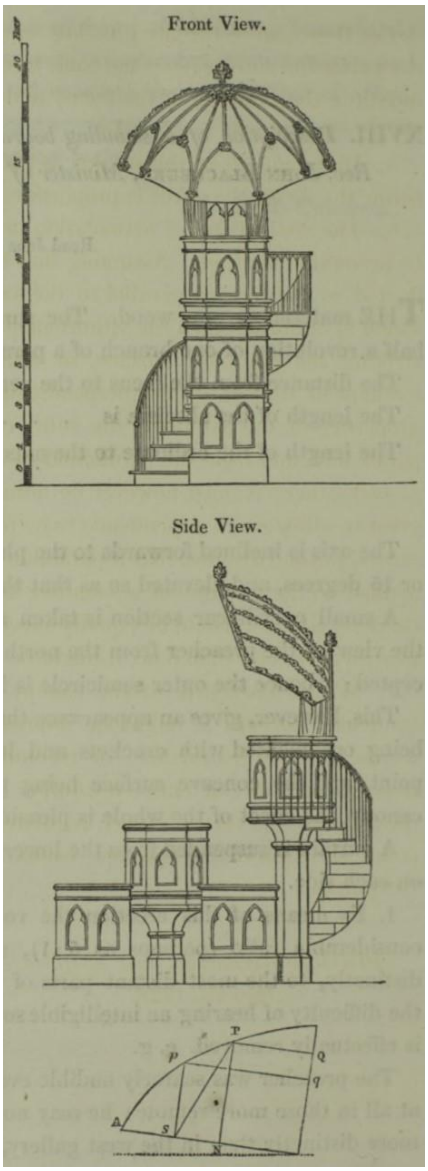

Figure 1: John Blackburn's depiction of his sounding board and pulpit in Attercliffe Church, published in 1828 in the *Philosophical Transactions of the Royal Society*, (Author's image, 2021).

In total, more than thirty churches across Britain followed Attercliffe's example and erected sound-boards, including Darnell church, Trinity Church at Huddersfield, two in Oxford, and both St Philip's and St Sepulchre's churches in Sheffield. The final parabolic installation took place at Duckenfield in the mid 1850s, suggesting a nationwide dissatisfaction with the acoustics of the post-1818 Anglican churches that were supposed to spiritually revive the country. Many of these sounding-boards, however, had been pulled down by 1860, including the original at Attercliffe. Not only did these constructions disturb

the ears of a speaker, but they conveyed the whispers of congregations and generally proved unpopular with clergymen. Often it was found that, with time, a new church's acoustics improved as its walls and plastering dried out, making hearing tolerable, if not perfect.[xxx]

Unsurprisingly, experiments over the propagation of the spoken voice took greatest urgency in Scotland, however, that these anxieties over the spoken sermon carried greatest urgency, stimulating considerable acoustic experimentation. Both the established Presbyterian Church of Scotland and the Free Church, founded in 1843, emphasized the importance of speech in worship. Firmly grounded in the evangelical teachings of the Protestant French reformer, John Calvin (1509-1564), Scottish churches were sites of moral instruction. Little wonder then, that Scotland witnessed a far more intensive scientific investigation into the behavior of the voice within churches than in England. In 1838, the shipbuilder John Scott Russell (1808-1882) turned his attention to acoustics, with specific concern for churches and lecture rooms. Alarmed at the deficit of acoustic knowledge, Russell pursued an experimental program on speaking and hearing in lecture theatres, trialing different seating arrangements. He presented his findings to the Society of Arts for Scotland, arguing that the perfect room for hearing would be one in which an orator spoke directly to each auditor. For this, he recommended an increasingly elevated seating arrangement which formed a curve away from the speaker. This measured "isacoustic curve" should, Russell continued, be implemented in theatres and churches so that the sonorous undulations emanating from a lecturer or preacher fall "without interruption" on the audience.[xxxi] **(Figure 2)** As the son of a minister, the context of Russell's sonorous investigations was a deeply religious one. Throughout the 1830s, the Presbyterian Church was increasingly divided over its relationship with the state and its system of ministerial appointments and, in 1843, under the leadership of Thomas Chalmers (1780-1847), 450 evangelical ministers broke away to form the Free Church of Scotland in what became known as the "Disruption." This represented about a third of the Presbyterian

Church's clergy and created an immediate demand for some 700 additional churches. Scotland was soon home to a diverse selection of new ecclesiastical structures, exhibiting varying degrees of acoustic success. Given speech's importance within both Presbyterian and Free Church worship, many of these constructions employed Russell's acoustic curve for the arrangement of internal seating.[xxxii]

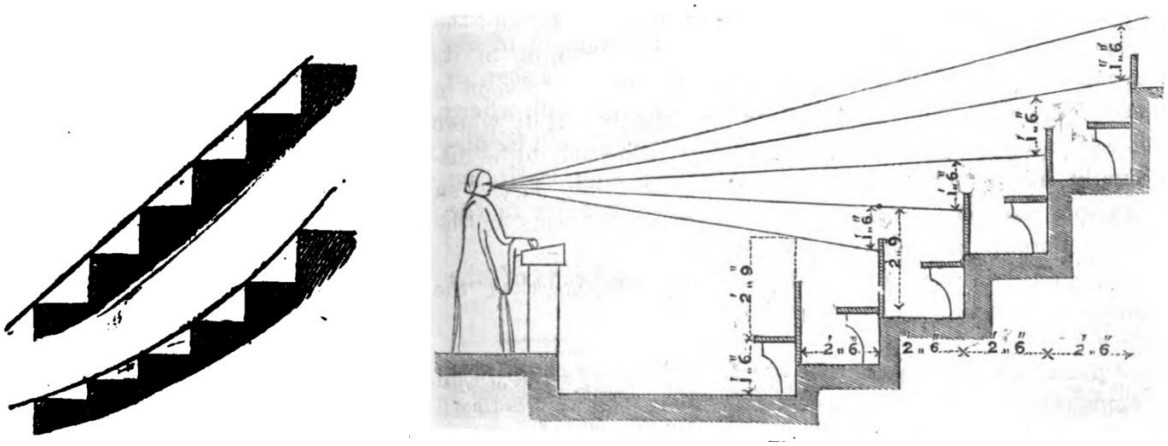

Figure 2: John Scott Russell's isacoustic curve, compared to the normal positioning of seating and as applied to seating in a lecture theatre or place of worship. These images were reproduced in Smith's *The Acoustics of Public Buildings* in 1861, (Author's image, 2021).

Given the centrality of speech within Anglican and Presbyterian rituals, focused on the communication of sermons, the importance of localized cultural and religious contexts to the development of modern acoustics becomes clear. In nineteenth-century Britain, this emphasis on the spoken word informed new understandings over how sound behaved. The significance of regional contexts for the history of acoustics becomes even more apparent if we compare the development of sound knowledge in the British Isles with that cultivated across the Channel, in Roman Catholic France. Here, the investigation of sound within churches took on a very different character.

2. France's Historic Church Soundscapes

In France, the cultivation of acoustic knowledge for religious buildings developed later, following the Revolution of 1830. As in Britain, France witnessed its own industrious church-building programme, resulting in some 9,000 new churches during the nineteenth-century.[xxxiii] While emerging from similar socio-political anxieties to those experienced in Britain, French concerns with the church soundscape took on a regionally distinctive character. The emphasis here was not on communicating the spoken word of the sermon but on the production of historical knowledge of the medieval church soundscape: this was about mobilizing the past for re-establishing the authority of the Church, particularly through the restoration of the historic sounds of worship, notably those musical. These differing liturgical and cultural priorities shaped very priorities for producers of sonorous knowledge working in the space of the church. This not only involved the organization of sung worship, but the restoration of historic acoustic techniques and instrumental innovation, specifically concerning church organs.

After years of political turmoil and the anticlericalism of the 1790s, in which religious buildings were often the targets of revolutionary violence, there was an increasing sense that France's dilapidated churches had to be restored to their past glories to reestablish public order and morality. What is more, in the application of the Napoleonic Concordat, which regulated church and state relations from 1802 to 1905, religious practice fell under the State's jurisdiction: public authorities legally had to ensure the provision of ecclesiastical buildings was proportional to the size of local populations.[xxxiv] By the 1840s, there was a growing consensus among France's architects, most prominently Eugène Viollet-le-Duc (1814-1879), that the moral regeneration of post-revolutionary society was inseparable from the revival of Gothic architecture. France's church building program was, therefore, characterized by historical inquiry and the production of archeological knowledge as a way of restoring a romanticized medieval spirituality. A crucial part of this was the restoration of the medieval

church soundscape, involving the revival of ancient liturgical practices. Musicians and clergymen were eager to restore the ritualistic chanting and polyphonic music so associated with Pope Gregory I (c.540-604) and Giovanni Pierluigi da Palestrina (c.1525-1594).[xxxv] Unlike British architects' focus on the communication of sermons, French architectural authorities often prioritized the musical qualities of churches. In his 1851 *Dictionnaire d'archéologie sacrée*, for example, the priest and archeologist Jean-Jacques Bourassé claimed that the elevated vaults of Gothic cathedrals were "very favorable to the performance of religious chant" and that "when the grave harmony of chant deploys itself in the choir … it spreads in undulating waves throughout the church."[xxxvi] Recapturing the soundscape of the Middle Ages was an architectural, musicological, and archeological challenge. This was not about producing places of audible sermonizing, but of reproducing the resonant qualities of France's medieval churches.

To oversee this renovation of French ecclesiastical architecture, the recently established Second Republican government appointed a network of administrators, archaeologists, architects, politicians, and clergymen to a commission for Religious Arts and Buildings in 1848. Three years later, the government replaced this with a body of inspectors, but the short-lived commission had, nonetheless, established the Gothic as France's dominant ecclesiastical style, satisfying those who thought medieval architecture to be acoustically superior to neoclassical constructions.[xxxvii] To secure historical authenticity, the empirical emphasis in French architectural discussions was not to produce experimental knowledge of sonorous phenomena, as in Britain, but aimed at retrieving lost, idealized, medieval soundscapes. Archeological discourse focused on the relationship between historic ecclesiastical materials and the sonic effects that these produced. For instance, speaking in 1877, Louis Besson (1821-1888), the Bishop of Nîmes, asserted that medieval church architects appeared to have undertaken their work "with a complete understanding of

harmony, willing to satisfy not only the eyes but also the ears." Marveling at the apparent acoustic perfection of medieval churches, in which "one still preaches with facility and where the spoken word bursts with an ease that doubles the strength of the orator," he concluded that recovering medieval principles of construction would ensure good church acoustics.[xxxviii]

Such convictions shaped archeological investigation into past acoustic practices, especially the use of sonorous apparatus. At the 1859 congress of the Société française d'archéologie, for example, discussions over the use of sound boards took center stage. Rejecting their practical value, the jurisconsult and archeologist Raymond Bordeaux (1821-1877) asserted that these devices had no place within a medieval church, being a post-Reformation invention and, therefore, inconsistent with the Gothic style.[xxxix] Likewise, in his 1878 treatise on church architecture, the historian Xavier de Montault (1830-1901) echoed Bordeaux's remarks from 1859, dismissing the use of the sound board in churches on historical grounds, asserting that "it certainly did not exist in the Middle Ages: its invention is essentially modern."[xl] This was a very different conception of the soundboard's potential value to that encountered in Britain, were such apparatus promised to materially aid sermonizers.

A particularly revealing example of how historic and sonorous knowledge was united within French architectural practice was the discourse surrounding the use of acoustic pots, or medieval vases between twenty and thirty centimeters long that were embedded in the churches' walls. Surrounding, these technologies were questions of historical accuracy and the practical value of past acoustic devices. In 1842, François Huard (1792-1856), director of Arles's museum, discovered "cornets of baked earth" in his local church of Saint-Blaise, whose openings were directed into the building. Huard speculated that these "must have served to echo sounds, and belonged to an acoustic system."[xli] Following this discovery, European archeologists uncovered similar contrivances in France, Sweden, Denmark, Ireland,

Russia, Hungry, the Balkans, and Lebanon, stimulating interest in these apparatus, with archaeologists speculating that they were made to resonate with the frequencies of a singing voice.[xlii] In 1862, the art historian and archeologist Adolphe Napoléon Didron published an inventory of these discoveries, sparking discussions throughout France's archeological communities, which Viollet-le-Duc later summarized in the entry "Pot" of his 1864 *Dictionnaire raisonné de l'architecture*.[xliii]

Nevertheless, historically determining the function of these pots was difficult. The only source to record their use, a chronicle from 1432, raised doubts over their efficacy.[xliv] In 1865, a clergyman named Bach claimed that medieval pots were very different to the ones that Vitruvius (c.80-70BC -c.15 BC) had described in his *De architectura*, alleging these to be acoustically advantageous. While ancient Greek vases drew on the acoustic qualities of bronze and the principles of resonance, being tuned to all 12 semi-tones of the scale, Bach contended that acoustic pots merely reflected sound.[xlv] Louis Besson went further and rejected the idea that these pots had been required at all, given that medieval churches were perfect and did not need to be corrected.[xlvi] Troublingly, here, was the implication that medieval builders had resorted to using resonating pots, which would undermine the idealized notion that Gothic churches had been acoustically perfect.[xlvii] In this sense, questions over the sonorous properties of vibrating pots were not just archaeological concerns, but engendered broader anxieties over how historic ecclesiastical soundscapes sounded, and how accurate knowledge of them could be attained.

However, this French emphasis on restoring a historically accurate, if idealized, medieval-church soundscape did not mean that France's ecclesiastical buildings were not sites of experiment and innovation. On the contrary, the restoration of the country's religious architecture and musical culture was inseparable from the development of new and effective technologies: church organs. These devices, the dominant musical instruments in church

worship, had long been a central object of philosophical inquiry. Yet in France, questions of organ construction and their use in worship took on increasing urgency amid state efforts to revive church architecture and music. The revolutionary turmoil of the 1790s had not only ruined France's ecclesiastical buildings but destroyed many of its church organs. In 1789, Paris boasted over a hundred organs, but by 1795 only 36 remained, several in a very poor condition.[xlviii] In 1813, the lawyer Félix Bigot de Préameneu, one of the main architects of the Napoleonic code, submitted a report to the Emperor, in which he detailed the dire state of religious music in the nation's cathedrals, which "for Sundays and feasts, have neither singers, nor organs."[xlix] Eager to use religion to reinforce his power, notably through the celebration of military victories and dynastic events, Napoléon initiated a policy of state support for religious music and organ building that remained in place until the end of the century.[l]

By the 1830s, in the context of an increased interest in religious patrimony among French political elites, and due to the clergy's eagerness to mobilize the instrument to draw congregations to the church, there was a growing enthusiasm for restoring and building organs. At the same time, changing musical tastes and European audiences' preference for more expressive orchestral performances encouraged organ builders to construct increasingly sophisticated devices, while world's fairs and the globalization of trade stimulated an intense competition between organ makers. All these transformations shaped new approaches to organ building, marked by unprecedented scientific and industrial standards of accuracy. Organ builders drew on existing philosophical discourse in their efforts to control the sound of these instruments. In turn, political and religious authorities resorted to acousticians to scrutinize the work of organ makers, fostering the production of new knowledge of sound.

The development of this more self-avowedly scientific manner of organ building first manifested during the construction of an instrument in the Saint-Denis basilica, the former

necropolis of French Kings. Having been subject to particularly violent revolutionary "vandalism," this church took on great significance within the state's restoration of religious architecture. In 1833, the government allocated a substantial budget for the construction of a new organ with the hope to select "the most beautiful and complete organ."[li] This ambition was reflected in the government's choice of Aristide Cavaillé-Coll (1811-1899) for this work, who became the nation's premier organ builder and leading authority in his field. Like other organ makers of his time, Cavaillé-Coll was eager to produce instruments of a broader tonal range, larger number of pipes, and a more precise system for controlling pressurized air, and became aware of how the thickness of pipes and pressure could deliver louder sound. In his proposal for the Saint-Denis organ, Cavaillé-Coll introduced significant changes in the distribution of air and the coupling of stops that promised to create unprecedented power and timbral variety. In addition to these features, the resulting instrument was the first to use the "Barker lever," a device the British organist Charles Barker (1804-1879) had developed to provide more power and responsiveness through greater control over an organ's valves.

State support to technological innovation in the organ became systematic after 1848, with the creation of an "organ" section within the Second Republican commission for Religious Arts and Buildings. Gathering organists, kapellmeisters, composers, musicologists, as well as an acoustician, a lawyer, and a judge, this body was in charge of studying bishops' demands of special funding for the construction or restoration of great organs in cathedrals.[lii] Driven by a faith in modern science and technology, the commission was eager to "encourage … all [the innovations] that tend to improve the instrument."[liii] This program materialized through the determination of national standards of great acoustic and technical accuracy for the construction or restoration of cathedral organs. Notably, the commission examined whether it would be suitable to impose the use of the Barker lever "every time we will have to deal with the building of new organs or for large restoration projects." Although the general

opinion was that this could give the unfortunate impression of the state interfering in private interests, the commission nonetheless took steps to bypass this difficulty by specifying "certain limits for the depression of the keys, the weight under which this depression will take place, and the degree of [this] depression."[liv] In addition to these specifications, the government imposed modern standards of tuning for the organ, including the use of a uniform pitch matching the practices of contemporary orchestras, as well as the implementation of equal temperament in all instruments.[lv]

To implement this national program of technological innovation, the French state introduced new modes of evaluation of the work of organ builders, marked by increasingly scientific procedures. In the eighteenth century, the task of examining new or restored instruments was eschewed to organ makers and players. In other words, judging the work of an organ builder required practical knowledge or professional skills. In contrast, the reception of Cavaillé-Coll's great organ at Saint-Denis in 1841 involved the participation of scientific authorities embodying more abstract and theoretical knowledge of sound. To scrutinize Cavaillé-Coll's masterpiece, the government appointed a commission formed by eleven judges, including acclaimed organists and organ makers, but also members of the Academies of Fine Arts and of the Sciences.[lvi] Among them were Pierre-Armand Séguier (1788-1867), the commission's president and a steam engines expert, as well as the mathematician and engineer Jean-Victor Poncelet who specialized in water wheels. The commission's conclusions were presented in a voluminous report addressed to the minister of Public Works, which reviewed in great details all the features of Cavaillé-Coll's instrument. In the following decades, these modes of evaluation of Cavaillé-Coll's work became the norm for the reception of state-funded organs in cathedrals, as well as in France's premier churches—with clergymen and parishes' administrators eager to utilize the prestige of acoustics to promote their newly built or restored instruments.[lvii]

The activities of these new organ commissions contributed to a recasting of the organ as an increasingly scientific object. The reception of Cavaillé-Coll's instrument at Saint-Denis in 1841 attested to this transformation, which created tensions between the various parties involved this process. On opening day, a large crowd had responded to the numerous announcements and invitations that Cavaillé-Coll had sent to the press, as well as to a great number of political, ecclesiastical, industrial, and artistic authorities.[lviii] In contrast to the expectations that such publicity had built among the audience, however, the reception of the Saint-Denis organ proved an immense disappointment. As one journalist reported, the far from being a brilliant spectacle, the committee's scientific focus ensured that the ceremony was a laborious affair. The session mostly consisted in the careful examination of the instrument, register by register, boring the audience who made their displeasure known; they allegedly "trampled" in sign of protest—which, the journalist concluded, was absolutely incompatible with the silence called for by the reception committee.[lix]

Although actors involved in the reception of state-funded organs remedied to these tensions by separating the scientific examination of the instruments from their artistic display, members of these bodies continued to cultivate ever-higher standards of scientific accuracy. In their report on Cavaillé-Coll's work on Notre-Dame's great organ, inaugurated in 1868, for example, the 16 members of the commission claimed that they met four times, and that "there was not a sound that was not heard, not a lever of this vast mechanism whose precision of movement we did not examine": "the acoustic part of the instrument was the object of a long and careful examination. The stops of every keyboard were trialed, pipe after pipe, and then grouped with one another."[lx]

With the development of these new modes of evaluation, scientific inquiry did not remain confined to the church. Rather, the result of organ commission's work often took the form not only of a handwritten report to the government, but also of a printed monograph

distributed by some of the nation's premier publishers. As part of organ makers' or church administrators' attempts to publicize the completion of a new instrument, and attesting to the popularity of scientific literature among French readers, excerpts of these reports also routinely appeared in the press, showing how the organ enabled the circulation of acoustic knowledge within broad segments of society.[lxi] The implications of these endeavors extended far beyond the church, as leading scientific authorities, including Hermann von Helmholtz (1821-1894) and Lord Rayleigh (1842-1919) looked to mobilize the practical knowledge of organ makers within their latest acoustic publications. The hard-won experiences of the builder and artisan, attained within ecclesiastical spaces, thus informed elite scientific knowledge of sound. But organs were also of particular musical significance, given that they were expected to deliver the sonorous qualities of a range of brass and woodwind instruments: the lessons drawn from organ building had implications for the wider study of musical acoustics.

3. From the Church to the Laboratory

In both Britain and France, churches were places in which sound knowledge was produced and applied, be it of architectural acoustics, historic soundscapes, instrumental innovation, or the sonorous properties of soundboards and acoustic pots. Different liturgical commitments shaped the extent to which these subjects were developed. Yet by the early twentieth century, the study of was increasingly relocated to the laboratory, as part of a wider reorganization of the natural sciences that was characterized by highly disciplined sites of scientific labour. MIT and Harvard both boasted centers of acoustic research, while Wallace Sabine's celebrated mathematical equation for calculating a room's acoustic properties was very much a product of laboratory trial.[lxii] After the First World War, specialist acoustic laboratories became even more prominent places of sonorous inquiry, as physicists, mathematicians,

architectural acousticians, and engineers looked to reorganize and standardize the scientific study of sound. With Hope Bagenal's professional architectural consultancy established in London during the 1920s, and Johan Holtsmark's opening of a custom-built autonomous acoustic laboratory at Norges Tekniske Høgskole in Trondheim, in 1929, the church was gradually usurped as a leading space of sonorous experimentation. And yet, in moving to the laboratory, acoustic science did not break with, but rather built on, its ecclesiastical origins.

This continuity was especially apparent in the transfer of organ-building skills and apparatus to elite scientific research. Organ pipes had long been objects of experimental inquiry, with William Whewell's 1837 *History of the Inductive Sciences* identifying a pipe's sonorous vibrations as one of the fundamental problems of acoustic science. Before Whewell, The organ pipe had been a valued experimental device for Mersenne, while eighteenth-century natural philosophers including Isaac Newton, Joseph-Louis Lagrange, and Daniel Bernoulli developed mathematical theory to account for how air oscillated within a confined space.[lxiii] Pipes remained central to the philosophical examination of sound in the nineteenth century, with Chladni, Herschel, and London experimentalist Charles Wheatstone all analyzing them in their work. But few had such practical knowledge of how sound operated within these artefacts as organ builders: to resolve the physical challenge of projecting music through churches, they contended with dramatic atmospheric changes that altered the ways in which sounds were heard. In comparison with secular music venues, churches presented remarkably unstable environmental conditions: it was in the church that understanding an organ pipe's sonorous properties was most important.

As Myles Jackson has demonstrated, organ building engendered a more practical treatment of organ pipes to traditional idealized mathematical understandings of these devices.[lxiv] Such work recognized that pipes were subject to material variations, including imperfectly positioned embouchures, alternative shapes, and differing temperatures and air

pressures. This amounted to a transformation in the study of these ecclesiastical objects as organ builders harnessed their practical, artisanal, know-how within the formation of new scientific knowledge. In 1860, Cavaillé-Coll delivered a lecture to the Académie des Sciences, sharing his observations concerning the relation between the length, depth, and shape of an organ's pipes and the wavelengths that these emitted.[lxv] Although scholars had tackled this question before him, Cavaillé-Coll boasted that since "in practice, we cannot always realize theory's isolated speculations, it was necessary to consider pipes with their usual embouchures and seek to put the theory in agreement with the facts."[lxvi] In particular, whereas mathematicians had theorized on tubes either with completely open or closed ends, the manufacturer asserted that such idealized pipes were not encountered in the practical business of organ building. To these problems, Cavaillé-Coll's response was to develop standardizing mathematical formulae which accounted for the differences between cylindrical and squared pipes.

Significantly, church organs presented challenges between frequency and atmosphere that were, in the nineteenth-century, unusual beyond spaces of musical practice. In particular, Cavaillé-Coll observed the impact of temperature variations on pitch. Already in his 1860 lecture, the organ builder took care to specify the temperature at which his calculations were valid: 15°C, this being Paris's average temperature, and the standard reference for scientists. In 1865, Cavaillé-Coll went further, warning Belgium's General Assembly of Catholics over the impact of temperature variations on the tuning of organ pipes. Armed with a wealth of experimental data, he detailed how "two organs tuned with the same tuning fork, one in the summer, the other one in the winter, could find themselves … at a quarter of a tone distance when they would be brought to the same temperature."[lxvii] Furthermore, churches were often humid, threatening the material integrity of an organ. In 1840, the composer Adolphe Adam praised Cavaillé-Coll's decision to replace wood with iron in several parts of the Saint-Denis

organ, a solution which prevented defects arising from "the swelling of wood caused by humidity and temperature variations."[lxviii] Indeed the Commission des orgues, established in 1849, identified humidity as one of the principal causes for an organ's deterioration.[lxix]

British organ builders were equally aware of the capricious nature of their instruments within church environments. The effects of temperature on an organ's pitch had first been analyzed in Robert Smith's 1749 *Harmonics*. As Master of Trinity College Cambridge, he had noticed tonal variations in the college chapel's organ and subsequently performed experimental measurements of this change. Smith calculated that one of the organ's pipes, sounding 268 vibrations per second on a hot August day, produced 262 vibrations in September, and just 254 vibrations in the cold of November. Within the fluctuating environment of Trinity's chapel, this single pipe therefore varied by up to half a tone, depending on the weather. This concurred with Newton's theory that the velocity of sound within an enclosed pipe changed in relation to the contraction or expansion of air that resulted from temperature variations.[lxx] Smith's experiments were well known to nineteenth-century British organ builders, with Hopkins detailing Smith's experiments in his 1855 treatise before explaining how the bodies of a congregation could warm exposed organ pipes, causing them to sound sharper.[lxxi] Likewise, in a paper on organ tuning, delivered to the Cambridge Philosophical Society in 1857, the mathematician Augustus de Morgan reported that professional tuners were keenly aware of the relation between tone and temperature.[lxxii] To compensate for these atmospheric challenges, organ builders trialed a range of solutions, including the installation of heating apparatus around the organ chamber to regulate temperature.[lxxiii]

In the mid- and late-nineteenth century, scientists were eager to draw on this practical knowledge, accrued through the construction of large organs for ecclesiastical spaces. Helmholtz's 1863 treatise, *Die Lehre von den Tonempfindungen als physiologische*

Grundlage für die Theorie der Musik, drew directly on the experiences of organ builders concerning both temperature and wind pressure. Helmholtz included a footnote detailing Cavaillé-Coll's mathematical formulae, which specified the exact ratios between a pipe's length, diameter, and its pitch.[lxxiv] Alexander Ellis, who had translated Helmholtz's treatise into English in 1875, also mobilized the experimental endeavors of organ builders. Ellis recalled how organ builder Henry Willis had, in 1865, "made a number of very careful experiments with organ-pipes, tuned by a slide on a slot, and actuated by bellows of constant pressure, of his own construction, with a view of determining difference of pitch by beats."[lxxv]

Mathematicians also found organ pipes to be invaluable experimental apparatus for acoustic analysis. Indeed, there were few individuals in nineteenth-century science who exemplified these links between the church and the laboratory so seamlessly as Rayleigh. Significantly, he was not just prominent within acoustic science but was also at the forefront of Britain's expanding laboratory culture, assisting Maxwell in organizing Cambridge's new "Cavendish" physics laboratory, opened in 1874, and succeeding Maxwell as the University's Cavendish Professor of Physics in 1879.[lxxvi] Rayleigh's scientific work overlapped both the physics laboratory and the church. In his *Theory of Sound* (1877-1878), Rayleigh drew attention to the to the behaviour of organ pipes. In particular, these revealed insights into the relationship between atmosphere and sound, as the "pitch of organ-pipes rapidly varies with the temperature and with the pressure of the wind."[lxxvii] Helmholtz, for one, was impressed with Rayleigh's development of mathematical theory "in the calculation of the influence of the open apertures of organ pipes and resonators upon their pitch." Helmholtz confessed that while his own analysis had focused on idealized cylindrical proportions, Rayleigh's treatment of pipes accounted for a greater "variation of conditions under which sound-motion takes place," providing mathematical solutions to pipes of a wide range of shapes and sizes. In this way, Helmholtz and Rayleigh adopted a similar approach to the development of mathematical

formula to that which Cavaillé-Coll had cultivated. Importantly, however, Helmholtz believed that Rayleigh's calculations for the oscillations of air within a contained space would be of value to those eager to understand how organ pipes sounded.[lxxviii] Such scientific knowledge seemed to have practical worth. Rayleigh continued these experimental investigations into the 1880s, refashioning the end of an organ pipe so as to be opened and closed with a paper slider. By mounting a tuning fork at the pipe's alternate end, Rayleigh measured the relationship between vibrations and adjustments to the paper slider to record the effects on the pipe's resonance. By the use of a "well-regulated bellows," he analyzed how changes in air pressure determined pitch, as exhibited by beats. He observed that a reduction from 4.2 to 1.53 inches of air pressure acting on the pipe gave a well-defined pitch, but below an inch of pressure, the pitch became graver.[lxxix] From this use of organ pipes as experimental objects, it is clear that ecclesiastical artefacts provided valuable materials for laboratory experimentation: the gradual refashioning of sound as an object of laboratory examination was marked by a transfer of church-cultivated apparatus and practices to the disciplined sites built specifically for the study of natural phenomena.

Rayleigh's experimental assistant, Arnulph Mallock (1851-1933) continued this research into the twentieth century. In 1918, he published a study on the effects of wind pressure on the pitch of organ pipes in the Royal Society's *Philosophical Transactions*, asserting that "the natural pitch of an organ pipe cannot be accurately determined from its material dimensions, but only by experiment." This was because so much of a pipe's pitch was contingent on the pressure of wind supplied. Rayleigh and Helmholtz had been aware of this but had not, Mallock contended, scientifically accounted for this phenomenon.[lxxx] Increasingly, scientists were treating pipes as complex devices, subject to variations in temperature and air pressure, and with awkwardly positioned embouchures, rather than as abstract mathematical ideals. As much as they were valuable laboratory apparatus, the

experimental examination of organ pipes invoked much of the capriciousness that organ builders encountered in the church.

The prominence of organ technology in laboratory culture extended beyond Britain. When Wallace Sabine's acoustic laboratory opened in Geneva, near Chicago, in 1919, it included a large organ and bellows for measuring variations in reverberation. The laboratory's architects calibrated the sonorous a sound chamber using "organ pipes whose rates of emission had been carefully determined", and future experiments employed "a complete organ of 73 pipes giving all tones from C (64) to C (4096)".[lxxxi] Likewise, Berlin's Physikalisch-Technische Reichsanstalt, established in 1887 under Helmholtz's direction, remained committed to an acoustic research program well into the twentieth century. As late as 1983, Werner Lottermoser's *Orgel, Kirchen und Akustik* drew on laboratory experiments conducted with ecclesiastical organ pipes.[lxxxii]

Conclusion

In nineteenth-century Britain and France, the production of sound knowledge owed much to the physical setting of the church. This was not unique to these countries; Chladni had employed similar sites in the German lands. Likewise, this was not limited to church design, with architects often concerned with the acoustics of secular buildings too, notably architect Gabriel Davioud's (1824-1881) Parisian theatres, and architect Theodore Lachez's 1848 *Acoustique et optique des salles de reunions*, focusing on auditoriums and halls.[lxxxiii] Yet in the context of British and French industrialization and socio-political unrest, which amplified long-existing tensions over the role of music and speech within Christian liturgy, understanding and disciplining sound in religious buildings took on increasing urgency. Our comparative analysis of these two regions is not, however, only pertinent because of these shared social, political, and moral anxieties, but because by contrasting various religious

cultures, we see how influential church spaces were on the knowledge cultivated within them. The centrality of speech within Scottish religious practice encouraged scientific inquiries centered on questions of intelligibility, while France's focus on historicism fueled investigations into past practices and devices, such as acoustic pots, for ensuring the euphonic propagation of chant and polyphonic music. In the Anglican Church, empirical investigations into acoustics engendered concerns over both music and speech. These differences reveal the religiously contingent character of nineteenth-century sonorous knowledge, as well as its inseparability to broader sociopolitical contexts. Our article began by claiming that churches were important sites of scientific activity: it concludes by emphasizing the shaping role of ecclesiastical architecture. This is not to imply spatial determinism, but rather that the theological and liturgical priorities attached to these places of worship influenced the nature of the knowledge fashioned in them. From our comparative investigation, it is clear that churches were not coincidental to, but crucial to, the character of nineteenth-century sound knowledge.

As acoustic science moved into the laboratory during the early twentieth century, as part of the broader reorganization, specialization, professionalization, and secularization of scientific practice, these religious origins remained evident. This shift contributed to what Emily Thompson has described as the "soundscape of modernity" in which the experience of sound was gradually separated from its implicit dependency on space. Where once, audibility was determined by physical environment, Thompson identified the rise of electroacoustic technologies and laboratory culture, between 1900 and 1933, as reconfiguring this relationship. This had, she asserted, a secularizing influence, with laboratory acoustics presenting "an understanding of the world fundamentally different from the divine ratios of the premodern cosmos" and that as "modern science took shape, architecture similarly lost its cosmological significance".[lxxxiv] While this period did witness a refashioning of American and

European soundscapes, the place of ecclesiastical space in acoustic science remained evident. Along with developing existing understandings of sonorous phenomena, originally experienced in ecclesiastical buildings, the organ ensured as a visible part of modern acoustic laboratory culture. And while this spatial reconfiguration was part of the gradual transition of sound from a sacred, to a scientific, object, the twentieth-century church did not disappear as a place of sonorous innovation and inquiry, with the management of sound still crucial to worship, be it through architectural design or new technologies, notably microphones and loudspeakers. Recognizing the historically complex relationship between sound knowledge and religious space emphasizes the culturally contingent nature of past sonorous inquiry.

---

[i] For spatial histories of science see, David N. Livingstone and Charles W. J. Withers (eds.), *Geographies of Nineteenth-Century Science*, (Chicago: University of Chicago Press, 2011); Crosbie Smith and Jon Agar (eds.), *Making Space for Science: territorial themes in the shaping of knowledge* (Basingstoke: Macmillan Press Ltd, 1998); Charles W. J. Withers, 'Place and the "Spatial Turn" in geography and in history', *Journal of the History of Ideas*, Vol. 70, No. 4, (Oct., 2009), 637-58.

[ii] Craig Wright, *Music and Ceremonial at Notre Dame of Paris 500-1500* (Cambridge: Cambridge University Press, 1989); David Hiley, *Gregorian Chant* (Cambridge: Cambridge University Press, 2009).

[iii] Francis Bacon, *Sylva Sylvarum: or a naturall historie* (London: William Lee, 1635), 46 and 67; also see, Leendert van der Miesen, "Studying the echo in the early modern period: between the academy and the natural world," in V. Tkaczyk and L. van der Miesen, ed., "Sonic Things: Knowledge Formation in Flux," *Sound Studies* 6, no 2 (2020): 196-214.

[iv] "Les lieux contribuent beaucoup à la cognoiffance de ce que nous cherchons." Marin Mersenne, *Harmonie universelle contenant la théorie et la pratique de la musique* (1636), facsimile, ed. F. Lesure (Paris: Éditions du Centre National de la Recherche Scientifique, 1963), 54.

[v] Nineteenth-century "Gothic Revival", however, we employ the term "Gothic" with reference both to the medieval and later styles, as is consistent with the language of our historic actors, often to emphasize the medieval accuracy of their works in contrast to eighteenth-century revival movements.

[vi] As Graeme Gooday has argued, to understand how past empirical inquiry was spatially contingent, we need to develop a broad understanding of the "kinds of spaces" that "have served as venues of experimental

epistemology". See, Graeme Gooday, "Placing or Replacing the Laboratory in the History of Science," *Isis* 99, no. 4 (Dec., 2008): 783-95, 785.

[vii] Alix Cooper, "Homes and Households," in Katherine Park and Lorraine Daston (eds.), *Cambridge History of science, Volume 3: early modern science*, (Cambridge University Press: Cambridge, 2006), 224-37; Anita Guerrini, "The Ghastly Kitchen," History of Science, Vol 54, No. 1, (2016), pp. 71-97; Simon Werrett, *Thrifty Science: making the most of materials in the history of experiment*, (University of Chicago Press: Chicago, 2019), 42-63.

[viii] "While we stand outside" a place of knowledge production, "we cannot see what goes on within … What we cannot see, we must take on trust or, trust being withheld, continue to suspect. Social life as a whole and the social procedures used to make knowledge are spatially organized." Steven Shapin, "The House of Experiment in Seventeenth-Century England," *Isis* 79, no. 3, A Special Issue on Artifact and Experiment, (Sep., 1988): 373-404, 374.

[ix] For examples see, Myles W. Jackson, *Harmonious Triads: physicists, musicians, and instrument makers in nineteenth-century Germany* (Cambridge, Massachusetts: MIT Press, 2006); Alexandra Hui, Julia Kursell, and Myles W. Jackson, "Music, sound, and the laboratory from 1750 to 1980," *Osiris* 28, no. 1 (Jan., 2013): 1-11.

[x] David Pantalony, *Altered Sensations: Rudolph Koenig's Acoustical Workshop in Nineteenth-Century Paris*, (Dordrecht: Springer, 2009); Sonja Petersen, "Craftsmen-turned-scientists? The circulation of explicit and working knowledge in musical-instrument making, 1880-1960," *Osiris* 28, no. 1, (Jan., 2013): 212-31; Michael Forsyth, *Buildings for Music: the architect, the musician, and the listener from the seventeenth century to the present day*, (Cambridge: Cambridge University Press, 1985).

[xi] For Roman Catholics like Augustus Pugin (1812-1852), for instance, Gothic architecture was calculated to arouse and sustain Christian feeling, especially through the senses, with a church's aesthetic beauty, modulated light, incense, and acoustics all acting to emotionally overwhelm congregations at God's mystery. Sound was essential to the church's power over its worshippers, with the Gothic's sensual influence complete 'when the deep intonations of the bells from the lofty campaniles, which summon the people to the house of prayer, have ceased, and the solemn chant of the choir swells through the vast edifice'. See, A. Welby Pugin, *Contrasts: or, a parallel between the noble edifices of the Middle Ages, and corresponding buildings of the present day; shewing the present decay of taste*, (London : Charles Dolman, 1841), 5.

[xii] Emily Thompson, *The Soundscape of Modernity: architectural acoustics and the culture of listening in America, 1900-1933* (Cambridge, Massachusetts: MIT Press, 2002), 18-9.

[xiii] M. H. Port, *600 New Churches: the Church Building Commission, 1818-1856* (Reading: Spire Books Ltd, 2006), 45; William Whyte, *Unlocking the Church: the lost secrets of Victorian sacred place* (Oxford: Oxford University Press, 2017), 1.

[xiv] Port, *600 New Churches*, 61.

[xv] Ibid., 95-100.

[xvi] Ernst. F. F. Chladni, *Treatise on Acoustics: the first comprehensive English translation of E. F. F. Chladni's Traité d'Acoustique*, (Tran.), Robert T. Beyer (Springer: Cham, 2015), 153-4.

[xvii] Ibid., 160.

[xviii] *Report from the Select Committee on House of Commons Buildings; together with the minutes of evidence taken before them*, Parliamentary Papers [PP]. 1831 (465), 12.

[xix] Ibid., 76.

[xx] Ibid., 74.

[xxi] David Boswell Reid, *Illustrations of the theory and practice of ventilation, with remarks on warming, exclusive lighting, and the communication of sound* (London: Longman, Brown, Green & Longmans, 1844), 310-28.

[xxii] On the religious customs of the House of Commons and the ecclesiastical continuities between the orginal chapel in use from 1547, and the post-1834 reconstruction, see https://www.parliament.uk/about/how/business/prayers/

[xxiii] Reid, *Illustrations of the theory and practice of ventilation*, 41-7.

[xxiv] John Blackburn, "Description of a parabolic sounding board, erected in Attercliffe Church," *Philosophical Magazine*, Vol. 6, No. 31, (London, England), 21-7, 21.

[xxv] Ibid., p. 22.

[xxvi] John Blackburn, "Description of a sounding board in Attercliffe Church, invented by the Rev. John Blackburn, Minister of Attercliffe-cum-Darnall, Sheffield," *Philosophical Transactions of the Royal Society of London* 118: 361-63, 361.

[xxvii] Blackburn, "Description of a parabolic sounding board," 24.

[xxviii] Ibid., p. 26.

[xxix] (Anon.), "The Rev. J. Blackburn's sounding-board for a pulpit," *Transactions of the Society Instituted at London for the Encouragement of Arts, Manufactures, and Commerce: with the Premiums offered for the years 1830-31 and 1831-32* (1831): 195-99, 199.

[xxx] Thomas Roger Smith, *The Acoustics of Public Buildings; or, the principles of the science of sound applied to the purposes of the architect and builder* (London: John Weale, 1861), 64-5.

[xxxi] John Scott Russell, "Elementary Considerations of some principles in the construction of buildings designed to accommodate spectators and auditors," *The Edinburgh New Philosophical Journal* 27 (Apr.-Oct., 1839): 131-36, 133.

[xxxii] Smith, *The Acoustics of Public Buildings*, 44.

[xxxiii] Jean-Michel Leniaud, *la Révolution des signes: L'art à l'église (1830-1930)* (Paris: Éditions du Cerf, 2007), 31; Nadine-Josette Chaline and Jeanine Charon, "La Construction des églises paroissiales en France aux XIX[e] et XX[e] siècles," *Revue d'Histoire de l'Église de France* 73, no. 190 (1987): 35.

[xxxiv] Leniaud, *L'Art à l'église*, 33; The Concordat system of Cults was established in France by the law of 18 Germinal year X (April 8, 1802), recognizing the Concordat concluded between the French State and the Holy See on Messidor year IX (July 15, 1801). Seventy-seven "organic articles," promulgated unilaterally by the same law, specified the application of the Concordat, affirm the preeminence of civil power over the Church and ensure the standardization of the Church in France. The Holy See continuously denounced them throughout the century. This regime was repealed by the law of Separation of the Churches of the State (December 9, 1905).

[xxxv] On Gregorian chant's "restoration," see especially Jean-Yves Hameline, "Le son de l'histoire: musique et chant dans la Restauration catholique (XIX[e] siècle)," *La Maison-Dieu* 131 (1977): 5-47; and Katherine Bergeron, *Decadent Enchantments: The Revival of Gregorian Chant at Solesmes* (Berkeley and London: University of California Press, 1988). On the revival of Palestrina, see in particular Katharine Ellis, "Palestrina et la musique dite "palestrinienne" en France au XIX[e] siècle: questions d'exécution et de réception", *La Renaissance et sa musique au XIX[e] siècle,* Philippe Vendrix (ed.) (Paris: Klincksieck, 2000), 151-184.

[xxxvi] "Quand au chœur se déploie cette grave harmonie du plain-chant … elle se répand en flots ondoyants dans toute l'enceinte de l'église." Jean-Jacques Bourassé, "Disposition," in *Dictionnaire d'archéologie sacrée*, vol. 1, (Paris: Migne, 1851), col. 1134.

[xxxvii] Notably, architect Georges de Villers had declared Gothic churches to be "preferable to Greek and modern edifices," as they did not exhibit the same "excess of sonority which sometimes affects the ears so unpleasantly in the latter." Echoing this view in 1857, trainee priest Oswald van den Berghe declared Gothic churches to be "excellent for acoustics" and noted that Notre-Dame de Paris was acclaimed predictor Henri Lacordaire's (1802-1861) favorite place for sermonizing, on account of its remarkable sonority. See, Oswald van den Berghe, "Le Temple du Graal. Suite et fin," *Annales archéologiques* 17 (1857): 293.

[xxxviii] "avec une entente complète de l'harmonie, voulant non-seulement satisfaire les yeux mais les oreilles"; "où l'on prêche encore avec tant de facilité, et où la parole éclate avec une aisance qui redouble les forces de l'orateur !" Louis Besson, "De l'acoustique dans les monuments religieux," *Bulletin du Comité de l'art chrétien (Diocèse de Nîmes)* (Nîmes: Jouve, 1877), 18.

[xxxix] Société française d'archéologie, *Congrès archéologique de France : séances générales tenues à Strasbourg, à Rouen, à St-Lo et à Vire en 1859* (Paris: Derache, 1860), 582-583.

[xl] "car la voix n'a aucune tendance à monter ; elle s'étend par ondulations horizontales"; "[l'abat-voix] n'existait certainement pas au moyen-âge : son invention est essentiellement moderne et les chaires citées ne dépassent pas le XV[e] siècle ; encore sont-elles des exceptions." *Traité pratique de la construction, de l'ameublement et de la décoration des églises selon les règles canoniques et les traditions romaines avec un appendice sur le costume ecclésiastique* (Paris: Louis Vivès, 1878), 229.

[xli] "Ces cornets en terre cuite devaient servir à répercuter les sons, et faire partie d'un système acoustique." Adrien de Gasparin et Adolphe Napoléon Didron, "Deuxième séance, mercredi 25 janvier 1843," *Bulletin archéologique publié par le Comité historique des arts et monuments* 2 (1842-1843): 440.

[xlii] Bénédicte Palazzo-Bertholon et Jean-Christophe Valière (eds.), *Archéologie du son. Les dispositifs de pots acoustiques dans les édifices anciens* (Paris: Société française d'archéologie, 2012).

[xliii] Didron, "Acoustique des monuments," *Annales archéologiques* 21 (1862), 294-97; Jean Benoît Désiré Cochet, "Archéologie monumentale. Poteries acoustiques," *Bulletin de la Société des Antiquaires de Normandie* 3 (1862): 557-564; "Séance du 8 juin 1865," *Bulletin de la Société d'archéologie et d'histoire de la Moselle*, 1865, 57-58; and "Séance du 10 août 1865. Travaux," ibid., 73-76. Viollet-le-Duc, "Pot," *Dictionnaire raisonné de l'architecture française du XI[e] au XVI[e] siècle* (Paris: B. Bance, 1854-1868), vol. 7, 471-72, 471.

[xliv] "Séance du 10 août 1865. Travaux," *Bulletin de la Société d'archéologie et d'histoire de la Moselle*, 74.

[xlv] "Séance du 8 juin 1865," *Bulletin de la Société d'archéologie et d'histoire de la Moselle*, 57-58.

[xlvi] Besson, "De l'acoustique dans les monuments religieux."

[xlvii] In his 1862 article, Didron quoted the chronicle, in which the author declared that he was not sure whether the pots had euphonically enhanced vocal performances within the church. Didron, "Acoustique des monuments," 296.

[xlviii] François Sabatier, "Musique et vandalisme, le destin de l'orgue en France entre 1788 et 1795," in Jean-Rémy Julien and Jean Mongrédien, (eds.), *Le Tambour et la Harpe. Œuvres, pratiques et manifestations musicales sous la Révolution 1788-1800* (Paris: Dumay, 1991), 45-59.

[xlix] Félix Julien Jean Bigot de Préameneu, *Rapport et projet de décret relatifs à la réorganisation des maîtrises des églises cathédrales en-deçà des Alpes*, 30 juin 1813. Archives nationales (hereafter AN), F/19/3947.

[l] In doing so, he was following the advice of his former minister of Cults, Jean-Étienne-Marie Portalis who, in 1806, had warned the emperor that "civil ceremonies and pomps are nothing, if they are not attached to the pomps and ceremonies of religion." Ministère des Cultes. Rapport présenté à Sa Majesté impériale et royale par le Ministre des Cultes, le 19 février 1806 (Paris: Imprimerie impériale, 1806), 2-3.

[li] Pierre Hardouin, *Les grandes orgues de Saint-Denis en France.* Special issue of *Connaissance de l'orgue* (1979-1980).

[lii] Amélie Dubreuil-Porret, "Contribution à l'étude de la restauration de la musique d'église du XIX[e] siècle au prisme de l'expérience de Félix Clément (1822-1885)" (PhD diss. Université Jean Monnet, 2016), 127-59.

[liii] Handwritten report by Paul Scudo et al.

[liv] Commission des arts et édifices religieux. Procès-verbaux des séances 1849. 1st May 1849. AN, F19/4545.

[lv] Handwritten report by Paul Scudo et al.

[lvi] *Rapport au ministre des travaux publics*, 1841.

[lvii] Fanny Gribenski, *L'Église comme lieu de concert. Pratiques musicales et usages de l'espace (Paris, 1830-1905)* (Arles: Actes Sud / Palazzetto Bru Zane, 2019), 179-241.

[lviii] Manufacture des grandes orgues Cavaillé-Coll [Paris], *Copies de lettres. Livre N5/1, 1840-1859*, BnF-Musique RES Vma MS-1364 [1]. See the copies of letters 219 to 264 (sent between 9 and 19 September 1841).

[lix] "Réception de l'orgue de Saint-Denis," *La France musicale*, 26 septembre 1841: 330

[lx] *Grand orgue de l'église métropolitaine de Notre-Dame de Paris reconstruit par M. Aristide Cavaillé-Coll. Extrait du rapport adressé à son excellence M. Baroche, Garde des Sceaux, Ministre de la Justice et des Cultes* (Paris: Plon, 1868), 10-11 and 12-13.

[lxi] For example, in 1844, an excerpt of the report on a new organ built in the church of Saint-Eustache in Paris appeared in *L'Univers*, one of the main daily newspapers at the time. "Orgue de Saint-Eustache construit par la maison Daublaine-Callinet", *L'Univers*, 12 July 1844: 4. Likewise, in 1846, *L'Illustration* printed part of the report on the newly built instrument of La Madeleine, along with a full page drawing of the organ and a diagram detailing the instrument's various stops. "Grand orgue de l'église de La Madeleine", *L'Illustration*, 7 Nov. 1846: 148.

[lxii] On Sabine see, Thompson, *The Soundscape of Modernity*, 253-9.

[lxiii] William Whewell, *History of the Inductive Sciences, from the earliest to the present time*, vol. 2, 3rd Edition, (London: John W. Parker, 1857), 255-57.

[lxiv] Jackson, *Harmonious Triads*, 118-20 and 134-46.

[lxv] "dans la pratique, on ne peut pas toujours réaliser les spéculations isolées de la théorie, il était nécessaire de considérer les tuyaux munis de leurs embouchures usuelles et de chercher à mettre la théorie en accord avec les faits." Cavaillé-Coll, "Études expérimentales sur les tuyaux d'orgues: de la détermination des dimensions des tuyaux en rapport avec l'intonation des mêmes tuyaux," *Comptes rendus des séances de l'Académie des sciences* 50 (23 Jan. 1860), 176-177.

[lxvi] Cavaillé-Coll, "Études expérimentales sur les tuyaux d'orgues," 177.

[lxvii] Assemblée générale des Catholiques en Belgique. Deuxième session à Malines, 29 août-3 septembre 1864. (Brussels: Comptoir universel d'imprimerie et de librairie, 1865), vol. 1, 462.

[lxviii] Adolphe Adam, "Orgue de Saint-Denis, *La France musicale* 3, no. 44 (1st Nov. 1840)": 391.

[lxix] Porret-Dubreuil, *Félix Clément*, 139.

[lxx] Robert Smith, *Harmonics, or the Philosophy of Musical Sounds*, (Cambridge: J. Bentham, 1749), 202-6.

[lxxi] Hopkins, *The Organ*, p. 186.

[lxxii] Augustus De Morgan, "On the beats of imperfect consonances," *Transactions of the Cambridge Philosophical Society* 10 (1864): 129-45, 129-130.

[lxxiii] Bishop, *Notes on Church Organs*, 16.

[lxxiv] Hermann von Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music*, 3rd edition (London: Longmans, Green, and Co, 1895), p. 89.

[lxxv] Alexander J. Ellis, *The History of Musical Pitch* (London: W. Tounce, 1880), 299.

[lxxvi] Simon Schaffer, "Physics laboratories and the Victorian country house," in Smith and Agar (eds.), *Making Space for Science*, 156 and 164.

[lxxvii] John William Strutt, *The Theory of sound*, vol. 1 (London: Macmillan and Co, 1894), 60.

[lxxviii] Hermann Helmholtz, "Lord Rayleigh's 'Theory of Sound'," *Nature* 19, no. 476 (12th December, 1878): 118.

[lxxix] Lord Rayleigh, "Acoustical Observations. – IV," *Philosophical Magazine* 5th Series, no. 82 (1882): 341 and 343.

[lxxx] Arnulph Mallock, "Note on the effect of wind pressure on the pitch of organ pipes," *Philosophical Transactions of the Royal Society* 95, no 666 (1918): 99-100, 103, and 106

[lxxxi] Hope Bagenal and Alex Wood, *Planning for Good Acoustics*, (Methuen: London, 1931).

[lxxxii] Werner Lottermoser, *Orgel, Kirchen und Akustik: Die akustischen Grundlagen der Orgel* (Francfort: Bochinsky, 1983).

[lxxxiii] Théodore Lachèz, *Acoustique et optique des salles de réunions publiques*, (Chec L'Auteur : Paris, 1848).

[lxxxiv] Thompson, *The Soundscape of Modernity*, 18-9.