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Architectural Acoustics: Thomas Roger Smith and the science of hearing buildings in nineteenth-century Britain

Graeme Gooday

> It is unfortunate that so few of the philosophers who have devoted their time to this study [of acoustics] have paid any attention to the most practical of all its possible applications, and that consequently an idea has become prevalent that nothing at all is known to men of science which would be of value to the architect.[1]
>
> -Thomas Roger Smith, A Rudimentary Treatise on the Acoustics of Public Buildings, (1861).

Who was responsible for optimising the aural experience of Victorian buildings? The Sheffield-born architect Thomas Roger Smith (1830-1903) lamented that physicists who wrote treatises on sound offered no practical advice on how their wisdom could benefit building design. Managing the many practical facets of acoustic science was, after all, a complex topic that the architectural profession could not obviously claim as its own sole prerogative. By contrast, architects were indubitably responsible for the external and internal appearance of buildings. Indeed writing as University College London's Professor of Architecture in the 1880s, Smith wrote histories of classical and gothic architecture that more conventionally prioritised instead the visual engagement of the 'spectator' as the principal sensory mode of experiencing a building. As the editors of this volume would surely emphasize, however, the congregations in medieval cathedrals discussed in Smith's historical writings were not art critics, but gathered instead to hear the liturgical rites of the Roman church.[2] Importantly, Smith's writings on acoustics from 1860 to 1895 not only discussed how developments in church architecture supported various soundscapes of religious participation but also showed more generally how architects could draw upon both acoustical theory and lessons from extant buildings to shape the aural qualities of future constructions of both religious and secular kinds.

This chapter sets out to contextualize Smith's acoustic expertise within the politics of Victorian Britain's architectural profession, as well as within contemporary public debates,

[1] Thomas Roger Smith, A rudimentary treatise on 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) 1-2. This was republished with an addition index as Acoustics in relation to architecture and building: the laws of sound as applied to the arrangement of buildings (London : Crosby Lockwood and Son. 1878). A third edition with minor additions was published as Acoustics in relation to architecture and building: the laws of sound as applied to the arrangement of buildings. (London : Crosby Lockwood and Son: 1895). Both later editions contain the same epigraph quotation at the pages marked. All page references to Smith, Acoustics below are identical for all three editions, unless otherwise specified.

[2] Thomas Roger Smith, Architecture, Gothic and Renaissance (London: Sampson Low, Marston, Searle & Rivington, 1884) 8. See also Thomas Roger Smith and John Slater, Architecture, Classic and Early Christian ((London: Sampson Low, Marston, Searle & Rivington, 1888).

and more recent historiography of acoustics.[3] Avoiding a purely biographical approach, the first part of this chapter puts into broader social context the kinds of debates among architects that prompted Smith's (intermittent) efforts to define the professional responsibility of architects in this area. In later parts, I explore how Smith's expertise was eventually eclipsed by the quantitative fin-de-siècle laboratory researches of American physicist, Wallace Sabine (1868-1919). As is well known Sabine's famous eponymous equation of 1900 for predicting and adjusting resonance periods was embraced as a new 'scientific' canon by many architects in the twentieth century.[4] To complement this, I show how Smith's critical qualitative approach to the aural ecology of buildings was the major reference standard among British architects for at least three decades since 1860 in ways previously unrecognised by architectural historians.

I thus reshape the interpretation of Smith's writings in Emily Thompson's study on American soundscapes which documents the ascendancy of Sabine's approach. She notes the conclusions drawn in 1895 by the 'Science Standing Committee' of the Royal Institute of British Architects (RIBA), that architectural acoustics was still an 'obscure' topic, and that Smith told this committee that it was still somewhat a matter of 'instinct' (i.e. based on personal intuition and thus not fully articulable). While Thompson infers from this that Smith had contributed little of long-term value to architectural acoustics, I show how Smith's various writings explicitly showed how to apply knowledge of 'the laws of sound' in ways that were based on much more than pure 'instinct'.[5] Overall I argue that understanding Smith's hitherto little-studied writings requires us to examine not only what was already known about building acoustics before Sabine's arrival, but also to take more seriously than historians have previously done Smith's alternative experiential approach to the 'science of architecture'.

The problem of acoustics in Victorian public buildings

The challenges facing the growing architectural profession in the nineteenth century were numerous: aesthetics, cost, hygiene, safety, utility, and acoustics, to name but a few. Architects had published lore to guide them in building centuries-old genres such as the theatre: generations of architects had brought their expertise to bear to ensure the acoustic success of plays and operas to paying audiences in enclosed metropolitan theatres.[6] Of

[3] For a discussion of the symbiosis between the writing of architectural history and the professionalisation of architecture in the nineteenth century see Katherine Wheeler, Victorian Perceptions of Renaissance Architecture (London: Routledge 2014). While Wheeler discusses Smith's historical writings, her study does not include acoustics. By contrast, for a discussion of acoustic issues in design of state-funded publics building in the 1840s, see Edward J. Gillin, The Victorian Palace of Science: scientific knowledge and the building of the Houses of Parliament, (Cambridge: Cambridge University Press, 2017) 30-1 and 140. For the deliberations of the select committee on the Houses of Commons' buildings see Parliamentary Papers 269 (1833), pp. 11-13.

[4] Emily Thompson, The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900–1933 (Princeton N.J.: Princeton University Press; 2002) 33-42.

[5] Emily Thompson, 'Listening To/For Modernity Architectural Acoustics and the Development of Modern Spaces in America' in Emily Thompson and Peter Galison eds), The Architecture of Science (Cambridge MA: MIT Press, 1999) 253-80 on 258.

[6] George Saunders, A Treatise on Theatres. London: I & J Taylor, 1790, esp. 4-29 on acoustics. Discussed in Smith Acoustics, 33-36 and in Emily Thompson, The Soundscape of Modernity, 21-24.

course, acoustical considerations to ensure the clear projection of a human voice to all present in the building were by no means paramount in all larger scale architectural endeavours of the Victorian period. It was not necessary in the design of hundreds of railway stations, factories, and libraries; and for the discreet commercial transactions of elegant new Corn exchanges, the priority was instead for localized transactional conversations that were not transmitted across the entire building.[7] Yet other new kinds of grandiose project brought unprecedented challenges for acoustics, specifically new civic edifices serving the public function of oratorical spaces or as concert halls. For such cases there was a cultural premium attached to architects accomplishing a soundscape in which human utterances could be heard and understood without distracting repetitive echo or the deadening dullness of un-resonant sound.[8]

The issue of acoustics was a particular problem for the swathe of town halls built across England from the 1820s as civic sites for all classes to attend public concerts, lectures, and assemblies of myriad other kinds. Smith himself noted in 1861 that large school-rooms, lecture halls, assembly rooms, and indeed the majority of moderate-sized halls built since then were 'very liable to acoustic defects'. Two factors in architectural practice were typically the source of problems: ill-judged building proportions and inopportune surface finishes. The former of these involved large empty spaces above or behind a performer: these could either dissipate sound into inaudibility or produce persistent echoes that distorted speech's clarity and or intelligibility. As for the latter, while sound scattered by highly decorated surfaces avoided direct echoes, a performer directly facing plain flat surfaces would typically encounter unhelpful reverberations that compromised the audience's appreciation of words said or sung by them.[9]

Smith's early writings tactfully focused on successful exemplars of town hall acoustics produced by fellow architects. As a model specimen he recommended in particular the Manchester Free Trade Hall completed in 1856, while passing in silence over the problems at the Town Hall in nearby Stalybridge. Rachel Milestone notes that the latter, built in 1831, was so prone to both acoustic and aesthetic defects, that it had fast become a laughing-stock. So much so, in fact, that when the town's Mechanics Institute was opened in 1862, all musical events in Stalybridge were abruptly transferred to that new venue. After remedial building work some concerts returned to the Town Hall eight years later. Yet the acoustics were not sufficiently improved to impress a reviewer from the Ashton Reporter in 1876 who discerned that 'defective acoustic properties of the hall were rather painfully apparent', with multifarious echoes preventing 'thorough blending' of the vocal and instrumental parts'.[10]

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[7] Smith, Acoustics, 136

[8] T.B. 'The acoustic properties of rooms', The Builder 19(1861) 469-70. One possible identification of T.B. is Thomas Talbot Bury, (c.1809-1877). Tregellas, W. (2004-09-23). Bury, Thomas Talbot (bap. 1809, d. 1877), architect and engraver. Oxford Dictionary of National Biography. Retrieved 4 Jan. 2018, from http://0-www.oxforddnb.com.wam.leeds.ac.uk/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-4156

[9] Smith Acoustics 134

[10] Rachel Milestone, 'The Monstrosity of Bricks and Mortar: the Town Hall as a Music Venue in Nineteenth-century Stalybridge' in Rachel Cowgill and Peter Holman (editors) Music in the British

This Pennine town was evidently not the only one to suffer so.[11] In the month immediately following Smith's 1861 publication of his Rudimentary Treatise on the Acoustics of Public Buildings, the topic was discussed in The Builder, a weekly periodical designed to appeal to architects, builders, and all fellow professionals engaged in associated processes. One correspondent, 'T.B', wrote in July 1861 deploring the discovery that the recently constructed Town Halls of Blackburn and Leeds, and of St George's Hall in Liverpool were 'sadly defective' as regards their acoustics. T.B. contended that most readers of The Builder would admit that architects had a special responsibility in ensuring the 'edification and pleasure' of audiences in such buildings. Few were unaware of

> … the difficulty we experience in hearing clearly and correctly public speakers, preacher and singers, in most of our churches; and particularly in our great public buildings, especially in some parts of the buildings. This does not so much arise from the deficiency of the speaker or singer as from the peculiar size, dimensions or proportions of the buildings.

Although various remedies had been tried, T.B. contended that up until that point no attempted mitigation of acoustic difficulties had been found that could completely 'remedy the evil complained of'. In his view the only architectural space in Britain which approached 'perfection' was the Cheltenham Pump-room in the spa town of Harrogate; this had been erected with Doric columns in the neoclassical style from the designs of 'Mr. Clark of Leeds' in 1833.[12] Laying out the dimensions of this building, the writer surmised that the architect might have 'happily', and probably fortuitously, hit upon the best proportions for a building to have optimal acoustics. T.B. conceded that while his judgements for the ideal dimensions of this room did not conform to the guidance in Roger Smith's recently published Treatise, Harrogate's Pump-room was nevertheless, 'an example of a good room to be heard in'.[13]

As a final example of acoustically troublesome architecture, the Royal Albert Hall, constructed in South Kensington from 1867-1871, was evidently not built to the recommendations of either Smith or 'T.B'. Designed to surpass in sheer grandeur any other building of its kind in Britain dedicated to the arts and sciences and in keeping with Queen Victoria's wishes for her late lamented Prince Consort, this gigantic tribute was the work of

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provinces, 1690-1914 (Aldershot, England ; Burlington, VT : Ashgate Pub. Limited, 2007.) 295-323, 309 & 311.

[11] The Belfast city hall completed in 1906 had problematic acoustics attributed to its high roof see: [Anon] 'Acoustic Properties', Architects magazine, 6.71 (Sep 1906) 203. For later discussion on problems at London County Hall, see 'Defective Acoustics.' Times 24 July 1922: 13.

[12] The Pumproom's dimensions were given b: inside length, 86 feet 6 inches; width 33 feet 0 inches; Height to ceiling line, 22 feet 7 inches; and height to centre 24 fet 2 inches. The architect in question was John Clark of Leeds (1798/9–1857), See Derek Linstrum, 'Clark, John (1798/9–1857)', Oxford Dictionary of National Biography, Oxford University Press, 2004 [http://0-www.oxforddnb.com.wam.leeds.ac.uk/view/article/63001, accessed 6 Sept 2017] . http://www.harrogatepeopleandplaces.info/publications/hollins1866/006-The%20Cheltenham%20Pump%20Room.htm Known latterly as the Royal Pump-room, this was repurposes in 1953 as a museum http://www.yorkshirepost.co.uk/news/through-the-years-taking-the-waters-in-harrogate-1-6728565

[13] Smith Acoustics 139-141, T.B. 'The acoustic properties of rooms', 470. The Builder had published a review of Smith's book the previous week (see below) 433-44, and a friendly adviser had clearly drawn T.B.'s attention to this volume at a late stage in the writing of this letter to the Builder.

two Royal Engineers: Captain Francis Fowke and Major-General Henry Scott. To commemorate the Prince's huge cultural legacy, the eponymous hall was modelled on classical amphitheatres: Rome's elliptical open-air Colosseum was one apparent model. Nevertheless, the addition of a high domed glazed roof of wrought iron to mitigate the inclement weather of Northern Europe was both entirely un-classical in credentials but also brought a long legacy of acoustic problems to this grandiose edifice. Following the completion of the Hall on Christmas Day 1870, these problems soon became apparent. Noting the unprecedented size of this construction, an editorial published in The Times on the day of its official opening (29 March 1870), alerted readers to anticipated difficulties:

> There are misgivings that the Hall exceeds the scale fixed by the conditions of humanity, inasmuch as it is about twice as large as the largest building yet found to answer its purpose. But there are many possible appliances to assist the sight and hearing, and as yet we are but tiros [sic] in the science of acoustics. The Hall can hardly be worse for seeing or for hearing than the position of St Paul's under the vast and lofty dome ... All this remains to be ascertained, and corrected if necessary.[14]

To some deferential journalists at least the Prince of Wales' speech at the opening ceremony was audible; and John Tyndall, Professor at the Royal Institution, was evidently lucky enough to be situated in seats where no disturbance was apparent. Yet journalists seated elsewhere in the Hall reported problems of a persistent echo, and the ensuing concert revealed the more general acoustic problems engendered by imposition of the high domed roof. Fowke and Scott initially sought to manage the problem by hanging a large canvas 'velarium' below it to lessen the effective height of the hall and thereby shorten the duration of its echo.[15] Even so, Scott felt obliged to write to apologize to the audience via the correspondence column of The Times for the acoustic infelicities that more than a few had experienced. Correspondents in the Building News were also unsympathetic to the apparent disparity of experience among those occupying the 8000 seats. One 'C.E' (perhaps Civil Engineer?) dismissed the Albert Hall as 'nothing more than a bad concert-room, quite unsuited for International Exhibitions or scientific lectures of any description'. The canvas awning was the only appreciable acoustic improvement included in the Albert Hall for nearly eighty years; thus critics noted wryly of the Hall's echo that it was the only concert venue in Britain in which composers would be guaranteed to hear their new composition twice.[16]

So significant were the problems encountered with the Albert Hall that this building was one of the very few recent constructions to which Smith felt obliged to comment critically in the lightly updated (1895) edition of his treatise on acoustics. In contrast to the

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[14] 'To-day the QUEEN opens a magnificent edifice' [Editorial] The Times, Wednesday, Mar 29, 1871 p 9; see discussion in 'St Pauls Cathedral and the science of acoustics' Building News, Vol. 20, 31 March 1871, 249-50.

[15] The velarium was a type of awning used in Roman times, stretched over amphitheatres to protect spectators from the elements - not for acoustic purposes.

[16] Henry. Y. D. Scott, and John Tyndall, 'The Acoustics Of The Royal Albert Hall', Times 1 Apr. 1871: 11. Henry Y. D. Scott 'The Acoustic Qualities Of The Albert-Hall The Times Monday, May 01, 1871, 12 'The Echo in the Albert Hall' Building News vol 20 9 June 1871, p.461. See additional critical discussion in the same source 352-3, 477, 500. Leslie Chew et al. The Daily Book of Classical Music: 365 Readings that Teach, Inspire & Entertain (Irvine, CA, Walter Foster publishing: 2010) 35

variety of ceiling shapes that had proven to be conducive to high quality sound transmission, he judged the Albert Hall's ad hoc arrangement to be unsuccessful. Some parts of the hall still experienced unavoidably compromised acoustics, a point which he attributed to the coving which joined ceiling to walls:

> In the Albert Hall this cove – running round an elliptical building – appears to be injurious rather than helpful, as it throws down an echo from such loud sounds as are able to pierce the canvas velarium, and concentrates the echo upon individual parts of the auditorium, where it becomes unpleasantly perceptible.[17]

Indeed it was mainly the identification of acoustic defects of buildings erected in the thirty-four years since the book's first publication that Smith devoted attention in material added for this second edition. Let us now turn to Smith's career to understand how he acquired such expertise in architectural acoustics.

Thomas Roger Smith and the emergence of architectural acoustics in Britain

A Fellow of the RIBA from 1863 and Professor of Architecture at University College London from 1880 until his death in 1903, Thomas Roger Smith was a well-known public figure in the Victorian profession. His reputation stemmed both from the buildings he designed in England and India, and the many public services he performed in Britain and its empire. Yet historical scholarship on him has focused either on his aesthetic reservations about the Gothic revival, or somewhat conservative (anti-nativist) views on the architecture appropriate for imperial India.[18] More recently, attention has focused on Smith's role in the RIBA's Standing Committee for Science.[19] Started in 1886, this technical committee addressed broader civic concerns among the architectural profession about the proper management of air, light, and hygiene via the most recent scientific research. What is not acknowledged, however, in any extant account is that Smith's career in architecture had a long association with science that dated back to his early writings on acoustics in the 1860s.

After private education in Sheffield, Smith was a pupil of London architect Philip Hardwick and after a year's travel set up an independent London practice in 1855. As Paul Waterhouse has stressed, Smith was a dedicated public lecturer, especially for the Architectural Association, which he joined in 1851 and for which he lectured on acoustics for the first time, in November 1858. He delivered his most substantial lecture on the topic at the age of thirty, to the RIBA in December 1860, effectively marking his arrival in the architectural establishment. While papers on the acoustics of architecture had occasionally

[17] Smith Acoustics 1895, 157-58

[18] Paul Waterhouse, 'Smith, Thomas Roger (1830–1903)', rev. John Elliott, Oxford Dictionary of National Biography, Oxford University Press, 2004; online edn, May 2006 [http://0-www.oxforddnb.com.wam.leeds.ac.uk/view/article/36163, accessed 28 Feb 2016]
J. Mordaunt Crook 'Architecture and History' Architectural History, 27 (1984) 555-578, especially 560-561; Thomas R. Metcalf, 'Architecture and the Representation of Empire: India, 1860-1910' Representations, 6 (Spring, 1984), pp. 37-65

[19] Sophie Forgan, 'Bricks and Bones: Architecture and Science in Victorian Britain', in Emily Thompson and Peter Galison, The Architecture of Science (Cambridge MA: MIT Press 1999) 181-208

been published in The Builder since 1846, Smith's lecture was judged to be of such importance that both Building News and The Builder published it in extenso.[20]

In assembling this lecture, Smith undertook a substantial amount of personal research, weaving personal acquaintance of the acoustic properties of buildings encountered in his travels together with wisdom gleaned from the few standard writings of British, French, and German architects that discussed acoustics.[21] As much time had elapsed since the RIBA had received a paper on this subject, and because so many sources on acoustics were inaccurate, he searched 'very thoroughly' for all pertinent information. He thus summarized the research of major scientific authorities on acoustics: John Herschel's treatise 'Sound' in the Encyclopaedia Metropolitana; Mary Somerville's On the Connexion of the Physical Sciences, and the writings of internationally renowned specialists such as Ernst Chladni.[22] Armed with this extensive knowledge of how much an architect could do to enhance building acoustics, Smith appealed to fellow architects now to embrace this topic as one of their core responsibilities. It was not enough, he declared for professional architects to produce buildings that were aesthetically-pleasing, well-ventilated, useful or hygienic:

> The proper construction of buildings intended for music or public speaking is a point of vital interest to every architect, as under this category may be comprehended all the more important works that come into our hands; and such buildings (however excellent in other respects) cannot certainly be said to have fulfilled the design with which they were erected, unless they had been made favourable to the easy transmission of sound.[23]

His analysis began with seven abstract principles of the propagation of sound as a vibration through a medium, and of the constitution of sound in frequencies of vibration, as demonstrated by the use of turning forks. Subsequently, he looked at the means available to the architect for influencing the transmission of sound, especially around obstacles and its movement to an audience. His models for this were the mirror (for reflected sound), the speaking trumpet used as a megaphone (for amplified sound), and the violin (for maximized resonance). For the first two of these, he observed that where sound underwent significant amounts of reflection around a room, some would hear speech or music at a different time or different volume to those situated elsewhere, often with echoes marring the sound. Conversely, a speaker with a very high ceiling above them would experience the effect of a speaking trumpet in a large empty space: much of the sound would be lost travelling upwards, making the hearing of words more difficult. Thirdly Smith advised architects to

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[20] Thomas Roger Smith,' On Acoustics', Transactions of the Royal Institute of British Architects, (1860-61), 73-96 (including discussion) republished as Thomas Roger Smith 'On Acoustics', The Building News 6 (1860), 992-997. Page references to 'On Acoustics' below are to the Building News publication . For discussion of his early lectures on acoustics in 1858-60 see Smith, Acoustics (1878) 160 and Acoustics (1895) 162.

[21]Theodore Lachéz . Acoustique et Optique des Salles de Réunions Publiques, (Paris: 1848) George Saunders, A Treatise on Theatres (London: 1790). J.G. Rhode Théorie der Verbreitung des Schalles für Baukünstler (Berlin 1800) and E.Chldani Traité d/Acoustique(Paris 1909).

[22] John F. W. Herschel, Treatises on physical astronomy, light and sound contributed to the Encyclopaedia metropolitana (London and Glasgow, Richard Griffin a& Co. (30 vols. 1817–45); Mary Somerville's On the Connexion of the Physical Sciences (London: John Murray, 1834).

[23] Smith 'On Acoustics' 993.

treat the violin as the epitome of how judicious configuration of resonating wooden components could naturally amplify sound without creating disturbing echoes; this technique was particularly valuable for aiding speech communication in larger buildings. Overall in Smith's view, combining these three elements to optimize acoustics was the architect's main creative challenge.

In this respect, religious buildings presented some of the greatest challenges to an architectural acoustician. In older stone edifices, such as Canterbury cathedral, the resilient resonance enhanced the sonority of music performed there, yet greatly impeded the comprehensibility of speech uttered by the clergy - unless the cathedral's resonance was dampened by the blessing of a large congregation.[24] Smith pointed out that in some other cathedrals, columns of stone were located so as to break up such uncongenial resonances, as could complex decorated vaultings. Yet these lessons had evidently not been embodied in the architecture of more recently built churches. This was somewhat ironic given the priority that Protestant theology placed (unlike the enjoyment of exquisite sonorities of sung liturgy in the Roman tradition) on ensuring that congregations heard each and every one of the clergy's words of salvation. Tall undecorated ceilings and plain reflective walls were indeed endemic in the 'low church' tradition in ways unconducive to well communicated sermons. Smith thus reported an invention some decades earlier by Rev. Michael Blackburn to mitigate the echo-prone effects of his high-roofed church at Attercliffe near Sheffield. The Rev. Blackburn's installation of a parabolic pine wood reflective sounding-board directly above his pulpit was essential to render his sermons properly audible to his congregation. This innovative way of refocusing speech from the pulpit toward the congregation can still be seen in numerous churches around Britain.[25]

From analysis of this successful technique for ameliorating acoustic difficulties in tall churches, Smith moved to investigate how to overcome the chief acoustic problems experienced in secular buildings: echoes, (excess) reverberation, obstacles, and 'unshapeliness, or bad proportions' (implying echoes). To avoid echoes, Smith advised that speakers or musicians should not be placed facing a flat wall directly opposite them, nor have any high empty space above them. Smith concluded that the Free Trade Hall in Manchester and the Philharmonic Hall in Liverpool met all of these requirements, which explained why the acoustic experiences in these buildings were judged to be so effective by audiences.[26] Indeed much of Smith's acoustic expertise had come from talking not to the architects of buildings that he visited, but to those who had direct and extensive experience of the sound world within them: 'in forming an opinion upon the success or failure of any public room or building, by far the surest guide is the account given of it by the persons who speak or sing in it'.[27]

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[24] Smith 'On Acoustics' 994.

[25] John Blackburn, 'Description of a Sounding Board in Attercliffe Invented by the Rev. John Blackburn Minister of Attercliffe-Cum-Darnall, Sheffield' Philosophical Transactions of the Royal Society of London 118 (1828) 361-363. At his RIBA lecture Smith showed a model of this sounding board which had previously been donated to UCL.

[26] Smith 'On Acoustics' 996

[27] Smith Acoustics (1878) 152

This unusual level of empiricism in audience research evidently caught the attention of one publisher, as Smith's lecture was immediately approached by Crosby, Lockwood & Co. to secure a monograph version for its 'Rudimentary Scientific Series'. At the time (1860) this Series comprised over three hundred books targeted at engineers, architects, builders, artisans, and students. It was in this specific context that Crosby, Lockwood & Co. published an expanded and retitled version of Smith's lecture as A Rudimentary Treatise on the Acoustics of Public buildings; or, the Principles of the Science of Sound Applied to the Purposes of the Architect and Builder (1861). This volume not only contained more detailed analysis of the above points, but also discussed the publications by civil engineer and naval architect John Scott Russell (1808 -1882) on the new topic of 'isoacoustics'. This was the principle of design deployed to accomplish equal hearing and visibility for all auditors seated in concert halls and lecture theatres. Such an analysis enabled Smith to explain the acoustic success of the Royal Institution's Lecture Theatre in Albemarle Street, which not only used suitably resonant wood and spaces of air in the traditional model of theatres, but epitomized 'isoacoustic' lines of sight and sound in its upwardly curving seating patterns.[28]

This Treatise received warm reviews. For example, The Builder in 1861 remarked that it was an 'ably written' volume, albeit on a topic that was 'not yet thoroughly understood'. Although Smith purported merely to have collected together the writings of others into a convenient form, The Builder considered it to be more than just a compilation: 'It is a professional view of acoustics as applied to the science of architecture and the art of building and well merits a perusal by others than mere tyros in professional practice'. The Builder in fact endorsed Smith's judgement of buildings 'successfully' constituted for acoustic success, and reprinted for its readers the relevant sections concerning the Manchester Free Trade Hall in extenso. [29] Unsurprisingly then, this book was the standard volume on the topic for the following three decades, with an additional edition (c.1878) which added an index. Finally, a slight revised and updated version in 1895 added material on both the new electrical modes of amplification and sound transmission (the telephone, microphone, and phonograph) as well as highlighting the continuing acoustic defects of the Royal Albert Hall.

Sabine vs Smith: algorithmic and experiential sciences of architectural acoustics

In Emily Thompson's historical accounts of architectural acoustics Smith's writings are acknowledged briefly, albeit as the putatively pre-scientific ancién regime. This is understandable since when Smith republished the new edition of his acoustics volume in 1895, his authority was clearly waning. In March that year, an Associate Member of RIBA, H.W. Burrows presented to a RIBA meeting a review paper on the status of acoustics as

[28] Smith, Acoustics, 43 and 104. John Scott Russell, 'Elementary Considerations of Some Principles in the Construction of Buildings Designed to Accommodate Spectators and Auditors' Edinburgh New Philosophical Journal 27 (Apr.-Oct. 1839): 131-36 and Transactions of the Royal Scottish Society of Arts, 1 (1841) 314-319. See discussion in Jeanne Halgren Kilde, When Church Became Theatre: The Transformation of Evangelical Architecture and Worship in Nineteenth-century America (Oxford: Oxford University Press, 2002) 48-57 and 234. For the broader history of the Royal Institution's architecture see Frank James and Anthony Peers, 'Constructing Space for Science at the Royal Institution of Great Britain', Physics in Perspective 9 (2007) 130–185.

[29] 'Books Received: A rudimentary treatise on the acoustics of public buildings', The Builder 19(1861) 433-34.

recently commissioned by its Science Committee. Noting the foundational status of Smith's RIBA paper of 1860 and his 'excellent' treatise the following year, Burrows nevertheless went on to highlight the many discrepancies in advice now apparent in the architectural literature about how to optimize building acoustics: 'the inherent difficulties of the subject are great, and they are by no means lessened, but amplified, by the strange divergence of opinion at times expressed upon one and the same point'. Significantly he acknowledged the rising authority of physics in this area: unlike Smith's confident deployment of acoustical theory, Burrows apologized for being 'merely an architect, not a physicist' and thus 'not fully competent' to deal with the science of acoustics in its 'abstruse bearings'. In the ensuing discussion Smith agreed that a new programme of systematic experimental research was needed to explain these discrepancies. Yet in focusing particularly on the recent discovery that atmospheric conditions could significantly affect a room's acoustic properties, Smith did not defer to physicists to produce the desired unanimity in architectural acoustics.[30]

As Thompson emphasizes, in that same year, one physicist began work that would, at least for some architects, bring about just such a unified approach. Wallace Sabine's use of experimental laboratory methods at Harvard produced a classic acoustics research paper which appeared serially under the title 'Reverberation' in American Architect and Building News between April and June 1900.[31] This publication contained the later eponymous 'Sabine Equation' which enabled quantitative predictions to be made of the echo period of a room even before it had been constructed. From knowing the effective volume (V) and surface area (A) of that room, and the average absorption coefficient of its surfaces (a), the reverberation time (T) could be calculated in feet as $T = 0.049\, V/Sa$ or alternatively in metres as $T = 0.161\, V/Sa$.

Smith and his co-workers produced this entirely empirical algorithm from investigating the troublesome reverberation in Harvard University's Fogg Lecture Hall: as originally completed in 1895 from designs by the pre-eminent US architect Richard Morris Hunt (1827-95) this room had a 5.5 second echo. This contrasted starkly with the echo time of just 1 second in Harvard University's Sanders Theater completed 1876, and considered thereafter acoustically ideal for speech transmission.[32] After detailed comparative investigations between the Fogg and Sanders theatres, Sabine and his team of student assistants formulated the universal equation mentioned above for calculating echo times in both locations. Moreover, Sabine formulated further advice on how to reduce excessive echo by deploying new sound-absorbent materials. Having solved Harvard's practical acoustic problem, this episode made Sabine's academic career as a university physicist, and enabled

[30] H.W. Burrows, 'Sound in its relation to buildings'. Journal of the Royal Society of British Architects, (3rd series) 2(1895) 353-75.

[31] As Emily Thompson notes, the definitive version of 'Reverberation' was reproduced as single article in Wallace Clement Sabine, Collected Papers on Acoustics (Cambridge MA & London: Harvard University Press, 1922, pp3-68.

[32] By comparison Sabine claimed the ideal resonance time for a concert hall was around 2 seconds. The Sander theater had been designed to mark the Centenary of US independence by Harvard graduates William Robert Ware and Henry Van Brunt for the University's Memorial Building. Their the model had been Oxford University's Sheldonian Building.

him to launch a successful side business as a consultant acoustician and manufacturer of sound-absorbent materials.[33]

Arriving as it did in a professional world of architecture marked by frustration at previous discordance among localised results in acoustic matters, it is easy to see why Sabine's locally-produced but universally applicable equation would have had appeal. And in a mood of increased deference to the disciplinary remit of physics in the early twentieth century, a number of British architects eventually embraced Sabine's acoustic science as a new canon for their field.[34] Yet this outcome was not immediately obvious at the time of Sabine's first publications. One architectural commentator reported critically in 1906 that his equation made no allowance for the well-known phenomenon that an audience-filled concert hall or lecture theatre would have a shorter reverberation time than an empty one.[35] Thus in 1911 an editorial in the Journal of the Society of Architects argued that the acoustics of buildings remained a 'difficult problem' without any clear authority able to resolve the key contentious matters. Instead this writer emphasised the value of Smith-ian qualitative wisdom in acoustic planning, e.g. that soundboards over lecterns and pulpits should be parabolic in shape.[36]

Nevertheless after his early death in 1919, Sabine's reputation as the new scientific authority on acoustics was given a considerable boost by the posthumous publication of his collected papers in 1921-22.[37] The leading British advocate of Sabine was Hope Bagenal (1888-1979), who had trained as an engineer at the University of Leeds before corresponding with, and then studying with, Sabine in 1914. In reviewing Sabine's papers six years later, Bagenal was moved to describe Sabine hyperbolically as the 'Isaac Newton' of architecture.[38] Similarly positive was Alexander Wood (1879-1950), the Cambridge University physicist at Emmanuel College: 'here at last is the greatest individual contribution to the subject of architectural acoustics made accessible to all'.[39] The advocacy of Bagenal and Wood, perhaps go some way to explaining how far Sabine's writing eventually became canonical in the interwar Britain as it was already in the USA.

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[33] Emily Thompson, The Soundscape of Modernity, 69-74. I thank Horatio Joyce for pointing out the it was Sabine's work with the Boston Symphony Orchestra and architect Charles F. McKim launched Sabine's consulting career before he left Harvard. See Thompson, The Soundscape of Modernity 69.

[34] For early praise of Sabine in the UK see [Anon] 'Acoustics and Architecture: reverberation and absorption'. Architects magazine, 1.5 (Mar 1901) 85.

[35] See discussions of this in the Builder's Journal, see [Anon] 'Architectural Acoustics'. Architects magazine 7.73 (Nov 1906) 15.

[36] [Anon] 'Acoustics of Buildings a difficult problem' Journal of the Society of Architects, 4.46 (Aug 1911) 372-373.

[37] Wallace Clement Sabine, Collected Papers on Acoustics (Cambridge MA & London: Harvard University Press, 1922.

[38] Hope Bagenal, 'Acoustics Applied to Buildings', Journal of the Society of Architects, 1922, 15.2 (Dec 1921) 34-46. David Trevor-Jones, 'Bagenal, (Philip) Hope Edward (1888–1979)', Oxford Dictionary of National Biography, Oxford University Press, 2004 [http://www.oxforddnb.com/view/article/63126, accessed 10 Sept 2017]

[39] Alexander Wood, 'Architecture And Acoustics' Architecture, 16.1 (Nov 1922) 40-42. On the collaboration of these two leading interwar UK acousticians see Hope Bagenal &Alexander Wood. Planning for good acoustics (London : Methuen, 1931).

Given such endorsements by leading acousticians such as Bagenal and Wood, it is easy to see why Emily Thompson's historical account emphasizes Sabine's explicit and quantitative claims to originality over Thomas Roger Smith's synoptic and mostly qualitative account. Beyond that we can also see in the early twentieth century a more conspicuous role emerging for mathematical equations in public scientific authority as epitomized in Albert Einstein's iconic equation $e = mc^2$ that correlated the energy of matter (e) to its mass (m) and the speed of light (c).[40] In a similar vein, Sabine's simple but powerful equation captured very clearly his authority as an architectural acoustician who seemed to have mastered a platonic abstract truth underlying the untidy contingencies of quotidian architectural acoustics. This particular valorisation of Sabine was also, I would argue, a sign of the professionalizing imperialism of twentieth-century physics: taking over problems in architectural acoustics, appropriating them to their disciplinary canon as if primarily the prerogative of acoustical physicists.

Yet we do not have to accept at face value that peculiarly twentieth-century representation of architectural science as an equation-based project of abstraction. As far as 'architecture as a science' was concerned, that was not obviously the archetype of what a science was in the second half of the nineteenth century when Thomas Roger Smith was writing on architectural acoustics. Indeed, Smith explicitly refused the idea that the subject was the algorithmic application of general abstract principles to particular cases. Instead he saw architectural acoustics much more as a sensitive discretionary craft which required great prior experience to be viable. The model he used in fact was that of the architect as a form of physician rather than a mathematician, with instincts informed by experiential practice, not platonic revelation:

> Practical architectural acoustics will always be in a position very much analogous to the practice of medicine. The physician, after he has gained all the knowledge of disease and of medicines which books can afford, is still quite unfit for actual practice unless he have the skill and intelligence to know how to vary his mode of treatment, and to suit his application of laws and principles to the different circumstances of each case, and the different constitution of each patient.[41]

It was in this respect, Smith argued, that acoustical work in architecture required a kind of instinct over and above any algorithmic rules, so that such rules could be applied most effectually to accomplish good effects:

> The most successful architects will tell you that their judgment of the probable acoustic effect of this or that arrangement is as much, or more, the result of a sort of instinct — a kind of internal perception of what will do, or what will not do.[42]

We can therefore revisit Emily Thompson's discussion of how Smith presented the status of his endeavours in 1895 before the RIBA Science Standing Committee as based on 'instinct'. Thompson implies that the absence of quantitative science explains why Smith could not

[40] Ian Stewart. Seventeen Equations that Changed the World (London: Profile Books, 2012).
[41] Smith, Acoustics , 2.
[42] Smith ,Acoustics , 2.

dissuade the RIBA committee from viewing architectural acoustics as still an 'obscure topic'.[43] In fact each edition of Smith's book on architectural acoustics opened with an exegesis on the 'science of acoustics' citing no fewer than seven propositions from contemporary physics on the nature of sound and its propagation. Indeed, in the wake of that RIBA discussion his 1895 publication of a third edition of the Treatise reiterated his approach thus premised on the science of acoustics which required discretionary application shaped by well-honed instincts. It was as if to remind the RIBA that his studies of architectural acoustics showed that this subject was neither obscure nor based solely on instinct.[44]

Also notable, in characterizing Sabine's putatively more 'scientific' practice, Thompson shows how his successful management of architectural acoustics was dependent not only on Sabine's equation but also on his development of special surface materials to suit each architectural case.[45] That latter development was not, however, exclusively Sabine's innovation since architects had long relied on bespoke material finishes to manage the acoustic properties of particular rooms. Smith had himself noted in 1861 how effectively specialist new material coverings on built surfaces could help to dampen or eliminate unwanted reverberations. He gave the specific example of the newly erected British Museum: to quell the echoes from the many polished surfaces, all chairs and desks were covered in leather, while the museum's floors were covered in 'kamptulicon', an artificial material of powdered cork in natural rubber.[46] Half a century later Sabine implemented a similar strategy but with the key difference that he did so with materials which he had himself patented. Since he did so as a physicist specialising in architecture rather than an all-round architect, posterity has paid rather more attention to Sabine than to Smith as the progenitor of architectural acoustics.

Conclusions

Upon Thomas Roger Smith's death in 1903, The Times' obituary of him recorded his writings on acoustics as just one of many among his impressive accomplishments as a leading professional architect in Britain. Alongside his teaching and scholarly obligations as a UCL Professor, he had been a successful public lecturer, professional consultant, designer of numerous building including the Post Office at Bombay (Mumbai), and wrote two histories of architecture and much else besides. Yet in an era that looked increasingly to sub-disciplinary experts rather than seasoned all-rounders to produce the key innovations, by 1903 Smith's characteristically Victorian breadth of accomplishment in architectural acoustics was no longer the (sole) basis of authority for what was becoming a new technical

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[43] Emily Thompson, 'Listening To/For Modernity', 258 & 273. The 1895 debate was reported in the Royal Institute of British Architects Journal (3rd series) 4 6 May 1897, 323.

[44] The publisher's prefatory note to this revised edition of 1895 specified that 'the text has been revised by him a in a few places, and additions made [on electrical transmission of sound and on the Albert Hall's defects]. Otherwise the text remains as in previous editions, the engagements of Professor Roger Smith having prevented his undertaking any comprehensive revision of the work.' Smith, Acoustics, 3d edition, .iv .

[45] Emily Thompson, The Soundscape of Modernity.

[46] Smith Acoustics, 40. Kamptulicon had been patented by Elijah Galloway in 1843/4: see entry on 'Floorcloth' in Encyclopaedia Brittanica, 11th Edition, Volume 10, http://gutenberg.readingroo.ms/3/5/7/4/35747/35747-h/35747-h.htm#ar24

specialism in the disciplinary domain of laboratory physics.[47] Yet to focus on why Smith was posthumously remembered for other achievements than his acoustical writings is to miss the point of this chapter.

I suggest that Smith's acoustic writings from 1860 to 1895 set a benchmark for his architectural contemporaries in the latter part of the nineteenth century. Unlike some, he did not treat the aural properties of buildings as irreducibly idiosyncratic, unfathomably mysterious, or simply not the architect's problem to resolve. Instead, his well-travelled practice embodied an understanding of architectural acoustics as an experiential science that necessarily combined the established principles of sound transmission with the lessons of past architectural ventures and the testimony of those who had performed in the public buildings he discussed. Given the comprehensive nature of his study, and his open-ness about freely sharing professional knowledge of various acoustical problems and their resolution, there was apparently little to add to his wide-ranging oeuvre for three decades. Accordingly, while he persuaded at least some architects to embrace professional responsibility for acoustic quality, he did not build a research school in the area as did Wallace Sabine from 1895. And it would seem that the extent and scope of architects' responsibility for acoustic matters has never been fully resolved.

Nevertheless, from a survey of Smith's writings, historians of nineteenth-century architecture can get a clearer sense of how far the lived experience of Victorian buildings was far from just being a visual (or even voyeuristic) encounter with decorated bricks and plaster. In many respects, to live and work in a building was to use it to communicate via its sound properties. This was rarely a trivial matter, and in an era before electronic amplification, it was (whether recognised or not) part of the architects' remit to minimize the problems of echo and diffusion that arose when building designs deviated from past precedents. Only by studying both positive and negative auditory experiences, whether through the ears of Smith or of his clients and confidantes, can we hope to recover a sense of everyday public life in Victorian Britain. In particular we might thereby understand better why some venues such as the Royal Institution in Albemarle Street were so successful for speech-based communication, and why others, such as the Royal Albert Hall, were not. Finally, the story of how architectural acoustics as a science developed by Smith as an architect for fellow architects (before appropriation by physicists) raises the broader question of how far we can see architects as active agents in shaping useful technical knowledge for their profession, not just passive recipients of science imported the physics laboratory.

[47] Obituary' [Thomas Roger Smith & others] The Times Saturday, Mar 14, 1903, 12.