ARCHITECTURAL ACOUSTICS IN AUSTRALIA

A few of the buildings of acoustical significance in Australia are briefly reviewed together with some of the people involved in architectural acoustics in the 20th century, their work, and the organisations and institutions for which they worked.

A NSW PERSPECTIVE

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INTRODUCTION

Most historical works covering the history of acoustics start with Pythagoras although music and musical instruments were in existence long before 600BC. There is anecdotal evidence that the study of sound in relation to buildings began before then (the Tower of Babel and the Walls of Jericho being two Biblical examples and the Greek amphitheatres another). Although these examples are not Australian and most can be assigned to the categories of myth, legend and prehistory, it is difficult to define what history is, what has had an effect on architectural acoustics in Australia and even what defines something as Australian. Hence this paper is a "partial" history in more ways than one.

The history of acoustics in Australia probably began about 60,000 years ago. This work has survived in Koori music, language and culture. That there was an interest in sound by the original inhabitants is indicated in one local language where the word for a peaceful quiet place is "anembo".

As far as most architects are concerned the history of architectural acoustics started, (and for many ended!) with Vitruvius Pollio, the Roman architect and engineer who wrote his "Ten Books of Architecture" 2000 years ago. For most of those practising architectural acoustics in Australia (and there are surprisingly few architects amongst them) or elsewhere, the subject began 100 years ago with the work of Wallace Sabine, at Harvard University, on the relationship between the decay rate of sound in a room and the volume of and absorption in the room.

Although there are some notable 19th century examples of surviving built works, such as the Great Hall at Sydney University, there is little dating from the first half of that century. Ross Thorne, an architectural historian who worked with Vivian Taylor nearly 50 years ago, has however documented the history of theatres in Australia [1]. But as there are very sketchy records of the development of theories, ideas and practice in the 19th century the history of architectural acoustics will be mainly taken as that of the 20th century. Even this presents considerable problems because a list of the titles of publications on the subject is large, the importance of the papers difficult to assess and anyway architectural acoustics is more than academic works. In fact the history has very little to do with written work and, where it does have, the written work is more often a standard or code than a research paper.

WHAT IS ARCHITECTURAL ACOUSTICS?

The field is fairly generally considered to cover room acoustics, perception of sound in rooms, speech intelligibility, the design of rooms for speech and music, the attenuation of sound by the building envelope and the interior partitions in a building, structure-borne noise and building services noise control. It obviously overlaps with such fields as noise control, vibration and impact, acoustic measurement and analysis, psychoacoustics and environmental acoustics, to name a few. As always there is considerable overlap of designated areas of acoustics, e.g. where does environmental acoustics end and architectural acoustics begin? Is sound propagation in air conditioning ducts architectural or duct acoustics and is the perception of speech in real rooms the prerogative those studying sound perception?

Architectural acoustics is commonly considered to be an art as well as a science but this comment largely applies to the "room acoustics" part of architectural acoustics. The reason for the "art", black magic etc is that there are so many criteria and variables to consider that it becomes possible to treat only parts of the subject in a scientific way. To some extent this accounts for the interest in the subject but, despite the best efforts of many workers, room acoustics remains shrouded in mystery.

SCOPE OF THE REVIEW

There are many ways of reviewing the significant work which has been done in architectural and building acoustics in Australia. One possibility is to list the papers that have been written on the subject but just this would take the whole of one issue of Acoustics Australia and even listing the papers of just one author on the subject would take more than the word limit for this paper. What to do? One could be selective and write about the papers that have had the greatest impact by giving the numbers of citations but this is a boring academic exercise of little use to anyone except bureaucrats pushing their political masters' barrows.

Architectural acoustics is, like most subjects, evolutionary rather than revolutionary. It is the practitioners who develop the subject as much or more than those who publish papers in learned journals. The development of building techniques and forms is greatly influenced by designs and ideas developed in other countries. How do we say what is "Australian" and what isn't? If it is built here is it Australian even though the building was designed elsewhere? If the building is built somewhere else but the architect or acoustical consultant is an Australian, is the building part of Australian architectural acoustics?

Architectural acoustics is also about teaching and learned society activities and standards and codes and consulting.

So this is the scope of the paper, like that of many histories, is subjectively defined. A work such as this must inevitably miss some important names and activities. What has been attempted is to give a brief overview and go into enough detail in a few cases to show that there is meat on the bones. What I have not done is to try to cover all aspects of the subject and so instrumentation, design methods, building products and materials and their suppliers have not been covered and nor have matters such as patents. Also, only the briefest of mentions is made of consultancies and software.

In case it may appear that there is a Sydney bias in the paper I would point out that there seems to be more interest in architectural acoustics in Sydney than in Melbourne or elsewhere in Australia. Most acoustical consultants are in Sydney for instance. It almost seems as though the amount of interest in acoustics is proportional to the acoustical problems encountered!

IN THE BEGINNING THERE WAS VIVIAN TAYLOR

Vivian Taylor (1894 to 1981) is the father of architectural acoustics in Australia. He was trained as an architect, started practising in Victoria in 1923 and at about the same time became interested in acoustics. He started working professionally in acoustics in 1928 on churches and public halls. His work on cinemas at the introduction of the "talkies" into Australia in 1929 is legendary [2,3]. From 1930 until 1941 his office acted as a consultant for at least 434 theatres and public halls.

In 1931 Vivian Taylor set up a reverberation chamber in Melbourne for the measurement of absorption coefficients of materials. Later he acted as a consultant on many prestige buildings such as the Houses of Parliament in South Australia and constructions such as the Circular Quay railway in Sydney. The ABC relied on him for acoustical advice from 1940 to 1956.

The following is a very brief mention of names of people involved in architectural acoustics in Australia. A few are covered in a little more detail elsewhere in this paper. (It is fully realised that there are many others who deserve mention and those mentioned deserve far more detail than there is space in this short paper.) Arthur Nickson, Roy Muncey, Werner Lippert, Bill Davern, Paul Dubout, Ian Dunn and John Davy have been at the forefront of architectural acoustics research at CSIRO in Melbourne from the late 1940s. Acoustical consulting and standards and Acoustical Society activities in architectural acoustics have been led by Vivian Taylor, Gerald Riley, Ken Cook, Anita Lawrence, Peter Knowland, and Graeme Harding. Other consultants who have made important contributions in architectural acoustics are Robert Fitzell (for projects such as Star City Casino and Fox Studios), Louis Challis (in particular for Parliament House, Canberra), Renzo Tonin, Peter Griffiths and many others. Ted Weston, at EBS, made an outstanding contribution to documenting the airborne transmission of sound through walls and developed a system for measuring the impact transmission properties of walls. Marion Burgess made important contributions at EBS, at UNSW and at ADFA. John Irvine was responsible for some of the early work on light-weight partitions in the CSR Acoustics Laboratory at Concord. Ernest Benson and Neville Thiele earned international reputations for their contributions to sound reinforcing systems.

SOME BUILDINGS OF NOTE

There is no such thing as "perfect acoustics" even though guides for tours of the Sydney Opera House frequently use the term and give anecdotal evidence about hearing pins drop on stage to prove it. What is more apt to describe the acoustics of some venues is a phrase Sir Thomas Beecham used to describe Dame Nellie Melba, "uninterestingly perfect and perfectly uninteresting". We strive for perfection and when we approach it, it disappears. "Schadenfreude" is a term that can be applied to our feelings about buildings as well as the misfortunes of people!

GREAT HALL, UNIVERSITY OF SYDNEY

The University of Sydney was the first university in Australia and the first building to be built, in the 1850s, included the Great Hall. The hall seats about 500 people and was an amazing inclusion given that the university started with about 20 students. The Great Hall was designed by Edmund Blackett but the basis for the acoustic design, if any, is unknown (a sobering fact for acoustical consultants!). One of the great claims to fame of the Great Hall is that Eugene Goosens, the conductor of the Sydney Symphony Orchestra in the middle of the 20th century, insisted on using the Great Hall for all the recordings he made with the orchestra. Dr Ernest Benson is also famous for the PA system installed in the hall which made speech intelligible for those over forty (and for many under forty). He was also the designer of a sound system for the Sydney Town Hall in the late 50s and the original electroacoustic system in the Sydney Opera House and St Andrews Cathedral and was a consultant for the loudspeaker design in the new Parliament House in Canberra.

CARCOAR COURT HOUSE

Carcoar is a small town in Western NSW between Bathurst and Cowra. It is a town that has been largely preserved as it was in its heyday in the late 19th century. Not only has the courthouse survived, but the acoustic treatment has survived as well. The treatment used is one that was used in the Royal Albert Hall in London in the early 1900s and subsequently removed. The acoustic treatment is miles of fine wire stretched under the ceiling of the court!

SIDNEY MYER MUSIC BOWL

The Sidney Meyer Music Bowl in Melbourne was the first large permanent outdoor concert venue in Australia. It broke new ground mainly because of the size of the venue and because it needed a sound system to enable the audience on the lawns behind the fixed seating to hear performances. Much of the work to achieve realistic sound was undertaken at CSIRO. Physical modelling techniques for design purposes were developed and research undertaken into the precedençe effect, column loudspeakers and signal delays in order to ensure the success of the venue.

SYDNEY OPERA HOUSE

Despite the lack of Australian content and a not altogether resounding success as a concert hall and opera hall there is one building which most practitioners mention as of prime importance in Australian architectural acoustics history and that is of course the Sydney Opera House. It is sometimes mentioned as the eighth wonder of the world and must be one of the few (if not the only) building to have an opera written about it. This is not just because it is the best known building in Australia and is despite the concert hall being severely bass deficient and having other problems and the opera hall orchestra pit having had more consultants with less resulting improvement than even Philharmonic Hall in New York. The solution in the case of the Philharmonic Hall (gut it and start again) cannot however be contemplated at the Opera House.

Besides being notable as a sculptural masterpiece the Opera House is also important because of the way the acoustics were "designed". One-tenth scale physical models were constructed on which V.G. Jordan undertook evaluations of several designs [4]. There were also Australians working on many aspects of the building. Peter Knowland was one of those and obviously learned much from the experience of working with two acousticians of world renown: Cremer and Jordan. It was a time of flowering for Australian architectural acoustics.

NATIONAL ACOUSTIC LABORATORIES

The Taj Mahal of Australian acoustics is the "sound shell" and the facilities in it at the National Acoustic Laboratories building in Chatswood, NSW. It is an extraordinary piece of architectural acoustics the like of which will probably never be seen again. The facility is a series of shells within a shell, built in an area of low background noise and ground vibration.

ANGEL PLACE RECITAL HALL

Sydney has long lacked a good recital hall. Other venues have been used with little enthusiasm either because of unsatisfactory acoustics, limited seating, or unsatisfactory backstage or front of house facilities. Peter Griffiths and Arup Acoustics have done a fine job on the acoustics and produced a hall that will be a benchmark for future halls in Australia in the 21st century.

RESIDENTIAL BUILDINGS

There are some residential buildings in Australia that are perhaps notorious rather than notable as far as architectural acoustics is concerned. Unfortunately, the libel laws are such that we dare not mention them and their well-known architects. (There is the famous case of a building in Canberra which was described as "leaking like a sieve". The newspaper and the writer of the article were successfully sued because it was shown that the building in question had only 127 holes in the roof whereas an average sieve had many more. There are several other notable examples including one where a cartoonist was involved.) It is these "failures" which are probably more important than the "successes" in progressing architectural acoustics but as mention of them has been driven underground mistakes continue to be made. Unfortunately there appear to be no houses in Australia of the notoriety of Frank Lloyd Wright's "Falling Water", which reputedly had the occupants continually wetting their beds, and the lesson seems to have been well learned (or else there is a lack of waterfalls to build houses over).

SANIP

What will be the biggest and most expensive architectural acoustics undertaking (and probably more expensive than all the acoustics projects ever carried out put together) in Australia is the Sydney Aircraft Noise Insulation Program (SANIP). Hundreds of houses and public buildings have been treated. This is an ongoing attempt at compensating residents under flight paths for the noise to which they are subjected. It was started after the introduction of the Third Runway at Sydney Airport, which was designed to not have a significant impact on the environment. The cost of the insulation program has been immense, even though the program has not been completed and it is only houses in the ANEF 30 plus areas (not ANEF 20 as suggested under AS 2021) that are being treated.

Overall the program appears to have been valuable but the attempt to reduce the wool stockpile by using it for ceiling insulation was a failure when the wool had to be removed after it became infested with beetles. Also, ventilation of many of the insulated buildings is unsatisfactory. The second biggest architectural acoustics project in Australia will be the evaluation of the SANIP. There has been no suggestion that this will be done but it must be undertaken if lessons are to be learned and money well spent in future.

OTHER BUILDINGS

Many of the cinemas, both new and old, are worthy of mention but a reference to another of Ross Thorne's books [5] will have to suffice. Theatres such as the Capitol Theatre in the Haymarket, the old Elizabethan Theatre in Newtown and town halls such as the Adelaide and Melbourne Town Halls and the Queensland Performing Arts Centre are also worthy of note. The Eugene Goosens Hall in the ABC building in Ultimo, Sydney, deserves a mention, as it was designed as a rehearsal space for the Sydney Symphony Orchestra with an acoustic similar to that of the concert hall in the Sydney Opera House.

Some restaurant guides in Australia now rate restaurants for their acoustics. This is a significant advance and hopefully will lead to a change from the hard reflective surfaces now in fashion. On the other hand publicans and restauranteurs know well that the noisier a venue is the more people eat and drink.

STANDARDS

Standards and codes have probably helped, hindered and distorted architectural acoustics in Australia more than any other factor. In the early days the standards committee on architectural acoustics was an important forum for discussions about the standards needed and served to transfer information on the theory and practice of many subjects, as there was a wide range of backgrounds among the committee members. There were too the seemingly endless (and sometimes pointless) arguments over matters such as the relative merits of dB(A) as opposed to NR.

That there was a need for standards (and for professionals to use them) was obvious from stories such as that of an architect who had conducted his own acoustic isolation test when residents complained that they could hear the "creaking bedsprings" in adjoining bedrooms of a block of units. The test consisted of the architect lying on the bed in one unit listening for the sound of his assistant "bouncing" on the bed in an adjacent unit. This method had the potential for being the basis for a very popular standard, though it would have required two people in the "source" room and the standardisation of the bed activity would have presented problems especially where multiple measurements were required. The AK/4 (AV/4) committee chose to write a standard based on a pink noise source rather than red-blooded passion!

The instigator of standards in acoustics in Australia and the first chairman of the AK/4 committee on Architectural Acoustics was Vivian Taylor. He was followed by Carolyn Mather, Fergus Fricke and the present chairman, Norbert Gabriels. On the committee there were consultants such as Peter Knowland, Gerald Riley and Graeme Harding. There were also representatives of building materials suppliers such as John Irvine and Arne Parts. The government labs were represented by the likes of Paul Dubout, Ted Weston and Prem Narang, while public authorities, the Australian Acoustical Society and universities were represented by Anita Lawrence, Marion Burgess and Ken Cook.

The AK/4 committee produced many important measurement standards but it will probably be best known for AS 2107 on recommended noise levels and reverberation times in buildings [6] and AS 2021 on the siting and construction of buildings around airports [7] which had its genesis in Carolyn Mather's PhD dissertation [8]

THE BUILDING CODE OF AUSTRALIA

The late Ted Weston is credited with the introduction of the acoustic provisions of the Building Code of Australia and its forerunner, Ordinance 70. Ted's attitude was that it was better to get some acoustic provisions into the building code than have none at all. At the time their introduction was being considered, he felt that if the proposed acoustic regulations were too stringent then nothing on acoustics would be included in the building code. He felt that once acoustic provisions were included they could be upgraded later.

Deregulation/private certification, urban consolidation, rapacious developers and inadequate acoustical requirements in the building code requirements have given architects, builders, developers and acousticians a bad name in many parts of Sydney. The situation is compounded by the problem of doing anything retrospectively to reduce the sound transmission between units or changing the BCA.

UNIVERSITIES

In NSW the best known universities for architectural and building acoustics are the University of New South Wales and the University of Sydney. Both of the NSW universities acted on the post-war recommendations of the Royal Institute of British Architects: that there was a need for more science and technology in architectural education. Jack Cowan was appointed as Professor of Architectural Science at the University of Sydney in 1954 and initially concentrated on structural aspects of buildings, but soon introduced environmental issues. At UNSW Ralph Phillips, Anita Lawrence and others were concerned with the environmental issues of lighting and acoustics, and Anita was responsible for the introduction of the MSc(Acoustics) degree. Early PhDs in architectural acoustics were awarded, at the University of Sydney in 1971 to Carolyn Mather for her work on the siting and constructing of buildings affected by aircraft noise (before that she did a Master's dissertation on noise in office buildings [9]), and to Laurie Hegvold, at the University of NSW, on the acoustic modelling of audiences.

In Melbourne, RMIT with Ken Cook and Elizabeth Lindqvist has also had an important influence on architectural acoustics. The work done on the sound transmission of roofs by Ken Cook has been of great value and there has been a long history of undertaking consulting and testing for industry. Mechanical Engineering Department at Monash University started out with a superbly equipped acoustics laboratory and the attention of Ron Barden and Cliff Stevenson. Len Koss, Robin Alfredson and others have since undertaken work of importance to architectural acoustics on impacts and the vibration of structures, barriers and enclosures.

Adelaide University has a proud history of acoustics research. While most of this work would not be classified as architectural acoustics some of the work that Dave Bies and Colin Hansen have done on subjects such as attenuation of sound in ducts and the coupling of structures to the acoustical field in a room are relevant.

For a while the universities in WA developed expertise in architectural acoustics with Harold Marshall and his co-workers, George Dodd and Michael Barron, and later when Harold Marshall moved to the University of Auckland, Tibor Vass and Derek Curruthers.

RESEARCH INSTITUTIONS

Undoubtedly the CSIRO Division of Building, Construction and Engineering (and its forerunner, the Division of Building Research) was the pre-eminent research institution in architectural acoustics. The work of Nickson, Muncey, Davern and Dubout on absorption of air and materials, acoustical modelling, speech intelligibility, the acceptability of late reflections in speech and music, room acoustics, sound reinforcement etc date back to the late 1940s. The results of their work have been published in nearly 150 CSIRO reports and papers in journals such as *Acustica* and *Journal of Sound and Vibration*, and in conference proceedings. John Davy, the current leader of the CSIRO group, has arguably done more to put architectural acoustics on a sound theoretical base than anyone else in Australia.

The National Acoustic Laboratories has not traditionally been involved in architectural acoustics but in recent years has made a significant contribution to measuring the sound transmission of walls and other building acoustics measurements.

The Experimental Building Station that later became the National Building Technology Centre and then, still later, part of the CSIRO Division of Building, Construction and Engineering, produced the authoritative work on sound transmission [10]. More recently, Prem Narang has been involved in the study of rain noise on roofs and the insulation of buildings against aircraft noise.

SEMINAL WRITTEN WORKS

Anita Lawrence's books, *Acoustics in Buildings*, published in 1962 [11] and her later works, *Architectural Acoustics* [12] and *Environmental Acoustics* [13] are the most important Australian architectural acoustics monographs, while the EBS Report 48 on the transmission loss of walls by Ted Weston et al. [10] was for many years the definitive work on wall performance. In terms of scientific papers the jury is probably still out and probably won't ever come back in or give a definitive decision. It has already been mentioned that papers by Muncey, Nickson, Dubout, Davern, Dunn and Davy have been published in the most prestigious acoustics journals. Fricke and his post-graduate students, eg Wu, Nannariello, Haan, Field and Mohajeri, have also published internationally in widely diverse areas of architectural acoustics but their work on assessing concert hall acoustics, the application of neural network analysis to acoustic problems and noise reduction through ventilation openings will probably be seen as their most important work. For anyone wishing to study architectural acoustics the lecture notes and demonstrations prepared by Densil Cabrera for the Masters program in engineering at the University of NSW are highly recommended.

OTHER WORK

There are some other developments that are worth mentioning. Amongst the most important are several pieces of software such as ENM and dBRay developed by Renzo Tonin and AutoSEA developed by Paul Bremner.

LOOKING TO THE FUTURE

Architectural acoustics is dying academically for a number of reasons, the two most important ones being that it gives little or no commercial advantage and has no strategic value. Part of the reason for the lack of interest from the building industry is that the provisions of the Building Code of Australia are so easy to comply with. Until the BCA is changed there will be little need for architectural acoustics research in an era of research driven by commercial necessity. Even if that changes, the research will be more than likely undertaken by acoustical consultants, as the time-scales that universities work to with PhD students are too long for most commercial interests.

Briefly, the future for architectural acoustics is mixed. There is a crying need for better sound isolation in many aspects of buildings and better predictions of subjective reactions to the acoustics of spaces. But unless the acoustics researchers can come up with ways of building better walls, floors, rooms etc there is little point in having architectural acoustics academics. Sadly there are no strategic reasons for putting money into architectural acoustics and there are few commercial ones for the reason indicated above and also because few developers or building materials suppliers see that they will get a commercial advantage from any research in Australia. In fact new acoustical products are often discouraged because, as one developer explained, "they draw attention to noise problems".

Architects seem to feel that acoustics has little or no place in a School of Architecture and, perhaps because of "Architecture" in the title, few other university departments seem to consider it as important. It is therefore left to the odd institution to carry the architectural acoustics torch. One such institution is the Acoustics Research Centre at Auckland University, but even that august institution is at risk from the economic rationalism broom that is cleaning out universities. There appears to be a reduction in the number of people working in architectural acoustics research and education and an increasing number working as consultants in Australia. Unless architectural acoustics continues to develop it will not survive. The future of architectural acoustics is not bleak, but it can hardly be said to be bright as the past.

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A VICTORIAN PERSPECTIVE

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In Victoria, also, there has been much activity in the field of architectural acoustics since the early 1920s. In this brief article, the emphasis will be on the activities of earlier workers, particularly those of H. Vivian Taylor, MBE, LFRAIA, FAAS (1894–1981), architect-acoustician, and of the CSIRO Division of Building Research, Highett, Vic and its team of acoustics researchers. While these, and more recent activities, are to be described in greater detail in a forthcoming account of acoustical work in Victoria, an outline will be given here.

H Vivian Taylor was one of the 20th century's early acousticians in Victoria. By 1923, when his interest in acoustics began, he had been admitted as an Associate to the Royal Victorian Institute of Architects and was registered and practising as an architect in Victoria, a practice subsequently extended to New South Wales. In 1931 he became a member of the Acoustical Society of America (founded in 1929), and was a foundation member of the Victorian Acoustical Society (1964), and first president of the AAS at its incorporation in 1971.

As architect and acoustician his earlier projects included some 55 churches, public halls, and industrial buildings. With the arrival of sound films ('talkies'), his projects after 1927 included at least 400 cinemas (many Hoyts), some as existing auditoriums whose acoustics he greatly improved, and some new, such as the Regal, Hartwell, and the 'new' Rivoli, Camberwell Junction, opened on 11 October 1940 and regarded in its day as a most modern cinema, complete with Crying Room for separating parents with young children from the rest of the audience [1]. He also designed public buildings throughout Australia, the SA Parliament House, ABC broadcasting studios in all states (including the original studios at William and Lonsdale Sts corner, Melbourne), and, during World War II, the Pagewood, NSW film studios, and, for the Australian Dept of Aircraft Production and the US Air Force, the silencing of the aero engine test cells for the SW Pacific area.

When Vivian Taylor began his acoustical work, Wallace Clement Sabine's (1868-1919) comprehensive *Collected Papers on Acoustics* [2] were amongst the few then available texts on architectural acoustics; the *Journal of the Acoustical Society of America* became available after 1929, with F R Watson's "Reverberation equation" [3], Vern O Knudsen's "Hearing of speech in auditoriums" [4], Walter A MacNair's "Optimum reverberation time for auditoriums" [5] and similar articles being published soon afterwards.

From these he learned not only of the influence of the reverberation time of a room or auditorium on the clarity and intelligibility of speech or music performed in them, and of ways of modifying this time to obtain its optimum for speech or music by introducing sound absorbent material to reduce excessive reverberation, but also of using appropriate materials for studios' and music rooms' walls, ceilings and floors as acoustic barriers to minimize the entry of unwanted sound from adjacent areas. A further development in obtaining optimum reverberation times arose from taking account of the average octave frequency spectra of speech and music sources, and, from these, developing a reverberation time vs frequency band characteristic such that, with corresponding acoustic absorption, all frequency components of the sound source would die away to inaudibility at the same moment.

In applying this experience he was able to design the interiors of cinemas, broadcasting studios, and auditoriums for speech and music to obtain good acoustics, through having shorter reverberation times (around 0.5 to 1.0s depending on room volume) for intelligible speech in cinemas and studios, and longer times up to 2.0s in studios and auditoriums for music. Because a single microphone is analogous to monaural listening, he found it important for broadcasting studios and other rooms to use lower reverberation times than for binaural listening conditions, and to eliminate all extraneous noise. These design procedures are described in detail in his 1938 Convention paper on "A new approach to architectural acoustic design" [6].

Because, in the late 1920s there was little information available about the acoustic properties of materials, he obtained the use of an office suite in 1931 for use as a reverberation room for assessing the properties of the acoustics materials then available [7].

As an acoustical consultant, Vivian Taylor also worked on community and other noise problems, with then current noise sources as varied as entertainment, industrial undertakings, mechanical plant, office machines, traffic and transportation. Where noise cannot be further reduced at its source, he argued that some form of noise zoning is necessary to preserve the acoustic amenity of an area or neighborhood. When the possibility of noise nuisance is taken account of and included at the design and construction stages of a project or piece of equipment, the resulting cost is considerably less than the "staggering cost" of subsequent remedial work. Noise zoning within a multi-dwelling or multi-use building is a matter of intelligent and proper planning and design; noise zoning within a multi-land use neighborhood needs an effective land use zoning ordinance. The 1957 Chicago Zoning Ordinance he considered to be "realistic, satisfactory and capable of enforcement" because it delineated and classified residential, business, commercial and industrial districts, and stipulated the permitted maximum octave band noise levels in decibels, as measured at the points of interest at zone/district boundaries [8].

His two available Convention/Conference Papers are those to the 1938 World Radio Convention, Sydney, on his "New Approach to Architectural Acoustic Design" [6], and to the 1971 AAS Noise Zoning Conference, Warburton, Vic on "The Economics of Noise Zoning" [8]. He was indeed a man of industry and imagination.

When in 1944 Ian Langlands was appointed CSIRO Officer-in-charge (from 1950 Division Chief) of Building Research he subsequently established an acoustics research group comprising Roy (later Dr) Muncey (from 1946), Arthur Nickson (1949), Werner Lippert (1950), Paul Dubout (1951) and Bill Davern (1957). As shown by their published papers, they embarked on an extensive research program into important aspects of architectural acoustics involving a judicious combination of pure and applied research.

Seven distinct aspects of this program can be identified : the acoustic properties of boundaries, acoustic models, room acoustics, sound amplification in auditoriums, miscellaneous building acoustics, community and other noise problems, and on the propagation of sound in air, ducts, etc. These CSIRO researches, largely based as they were on that of previous researchers, were a combination of both a review and confirmation of the earlier work under CSIRO laboratory conditions, and an extension of their conclusions into new areas. By 1960, this group had produced 40 research papers and reports.

Research into the acoustic properties of boundaries was undertaken because there were few data available on the absorption coefficients of the acoustic materials of that time. It was first concluded that coefficients should be calculated from measurements of the Specific Acoustic Impedance of each material. From earlier research there were eight methods then possible, of which the Transmission-Characteristic method was initially selected, and for which six carefully proportioned rectangular chambers were constructed having greatest chamber dimensions of 1.73, 0.864, 0.432, 0.216, 0.108 and 0.054m, for frequencies from 100 to 5000Hz, and normal and other angles of incidence [9]. With this equipment, specific acoustic impedances of materials either in situ or as samples could be measured. It was not until 1953 that an acoustic impedance tube was built for measuring the impedance of sound-absorbing material samples [10], including perforated facings backed with porous materials, with or without an intervening air space [11]. These latter were found to be very adaptable in that they could be designed for narrower or broader frequency band absorption characteristics, with maximum absorption coefficients around 0.9, and as high as 0.6 at 200Hz.

In 1950, the possibility of using architectural acoustic models for simulating room acoustics dated back to at least 1914, when W C Sabine did so as described in his paper (no. 7) on "Theatre Acoustics" [2]. However, much remained to be discovered. On the basis that the use of models (eg, around one-tenth full size) offered "tremendous possibilities for elucidating acoustic phenomena, for testing the acoustics of a new auditorium before its erection, and for making laboratory experiments and measurements", Roy Muncey et al, over a period of 6 years, demonstrated that a scale model of a room, with suitable bounding surfaces and interior atmospheric conditions, could, with accuracy to 0.05%, reproduce to scale the acoustical properties of the room. The overall "accuracy attained corresponded with the accuracy with which the surfaces were matched, and was considerably greater than that of the relation of objective testing and subjective impressions." [12]

Alongside the research on acoustic models, Roy Muncey, Arthur Nickson and Paul Dubout investigated several aspects of room acoustics, including auditorium reverberation times, listeners' judgments on room acoustics, and the degree to which listeners to speech or music were disturbed by echoes. With both speech and music echoes, they confirmed the "Haas effect" that an echo was not disturbing if it arrived within 30 to 50 ms of the initial sound, even if 10dB louder, an effect important both in the acoustic quality of auditoriums and in sound reinforcement [13].

Roy Muncey's and Arthur Nickson's work on sound amplification and reinforcement in auditoriums proceeded along two main lines, depending on whether or not the amplified sound as heard was later than the initial sound, and on the other characteristic of the Haas effect that the sound would appear to come from its source, however weak, as long as the amplified sound was heard just after the original. For the Melbourne Exhibition Building and medium size auditoriums and church interiors, a sound reinforcement system was found satisfactory provided that the loudspeakers (of a special column design to give maximum lateral and minimum vertical sound dispersion) were further away from listeners than the source. For large spaces such as the Myer Music Bowl, with the column loudspeakers placed close to the more distant listeners, suitable delays (to ca. 1s), calculated to use the Haas effect and simulate reverberation, were required. These delays were initially obtained through a magnetic tape recorder with continuous tape loop, later through other electronic means [14].

Researches into miscellaneous aspects of building acoustics were carried out to solve particular noise problems. Werner Lippert, in a paper on the latest developments [15], gave an account of the then current standards available, and the work done on designing walls and inter-floor partitions with improved sound insulation for multi-unit dwellings. Paul Dubout [16] described work done in predicting and reducing the interior noise levels from rain falling on metal roofing.

Their noise reduction work covered many aspects of both community and machine noise. In response to a request from the Melbourne City Council, an early noise problem worked on by CSIRO DBR staff was that of noise in the Degraves St subway, now Campbell Arcade, from trams in Flinders St overhead. The problem arose through the M&MTB re-constructing the tram track in solid concrete in intimate contact with the subway structure, without thought of the noise that wheel-on-rail vibration would cause in the subway. Against ambient noise levels of 65–70 dB(C) or 56–61 dB(A), tram noise levels in the subway were 85–102 dB(C) or 79–96 dB(A). The problem was remedied, and tram noise reduced by 13 to 15 dB, by spraying a vibration dampening rubber-based layer on subway duct work, disconnecting the shop walls from the ceiling slab, suspending the shop ceilings from these walls, and reducing the reverberation time in the subway to 0.5s [17].

If the tram rails had, instead, been supported on 20 mm deep longitudinally-fluted natural-rubber rail pads (of 40 IRH) and otherwise vibration-isolated from their concrete roadway (as currently over the Museum station concourse under LaTrobe St) the noise problem would not have occurred, for the vibration intensity in the slab would then have been reduced to one-tenth. This case illustrates a problem with which acousticians are continually faced, in that architectural, engineering and other designers too often fail, and sometimes even refuse, to take account of the acoustical and vibration implications of their designs, with the result that subsequent remedial work has to be undertaken, which invariably turns out to be significantly more costly than if noise and vibration reduction measures had been originally incorporated in the project or equipment.

While all CSIRO DBR acoustics staff were involved at one time or another in researches into the propagation of sound in air, ducts, filters, etc, as investigations supporting their other researches, much of it was described and recorded by Werner Lippert, who, between 1954 and 1965, published 15 papers, 11 in *Acustica*. Typical of these is his work on wave transmission around bends in rectangular ducts [18].

The acoustical work of Vivian Taylor and of the CSIRO DBR has been briefly described here because it has formed the basis of much continuing acoustical work, not only in architectural acoustics, but in the many aspects of noise and vibration measurement and reduction. It is only for reasons of space limitation here that the work of other Victorian acousticians, and groups such as at the Australian Acoustical Laboratory, Monash University, the PMG (later Telecom, now Telstra) Research Laboratories, RMIT, and of the numerous earlier and more recent acoustical consultants cannot be included here. However, accounts of some of their work can be found in AAS Conference *Proceedings* from 1968 onwards, and, from 1973, in the AAS *Bulletin* and its successor from 1984, *Acoustics Australia*.

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