FROM SOUND PROPAGATION TO SOUND PERCEPTION

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1 INTRODUCTION

This paper outlines the main content of the Rayleigh Medal Lecture, which reviews the author's work in the last 40 years, with a transformation from sound propagation focused to sound perception focused, along with the demanding from the society, to create a quieter, safer, more comfortable and sustainable sound environment.

The paper includes three main sections:

1) The work since 1983, focusing on sound propagation, namely the physical aspect of sound in our built environment, both indoor and outdoor.
2) The soundscape work in the last 20 years, along with the practical demanding of creating quiet areas required by the EU Directive [1].
3) The current work on the development of Soundscape Indices (SSID), based on an ongoing European Research Council (ERC) Advanced Grant project.

While this paper is relatively brief, more detailed information can be found from the video-recorded version of the lecture. For each research work mentioned in this lecture, corresponding publications are included in the Reference list of this paper.

2 SOUND PROPAGATION

2.1 Tsinghua

The author started his acoustic research in 1983 with his final year undergraduate degree project at Tsinghua University, Beijing. The aim of the research was to provide a recommendation value for the noise level limit of school classrooms in China, as a part of the State standard on school acoustics. In this research, the sound field in school classrooms was first examined, and the sound absorption of pupils in primary schools and middle schools was also determined. The relationships between noise level and Mandrin speech intelligibility, and the relationships between noise level and noise annoyance, were both examined based on a series of measurements in schools, and correspondingly, the noise level limit was determined [2].

The author then undertook a Master degree at Tsinghua University, examining the role of 'clouds', namely suspended ceiling panels, in auditoria. With computer simulation as well as 1:10 physical scale modelling, the reverberation process with different cloud parameters and absorption situations of the ceiling spaces was revealed [3], and the results were applied in a number auditoria design in China.

The author then worked as a lecturer at Tsinghua University, from 1987-1992. Among various research projects, he examined the most cost-effective ceiling sound absorption treatments for reducing noise in factories through a series of laboratory experiments, and those were applied in a number of practical noise control projects. It was also discovered that with a given noise level, people are generally more annoyed if this is associated with a longer reverberation time[4].

2.2 Fraunhofer

The author worked as a researcher at the Fraunhofer Institute of Building Physics, from 1992 to 1993, and then again from 1998-1999, as a Humboldt Postdoctoral Fellow. The main area was fibre-free sound absorbers, especially membrane absorbers with various kinds of material, including aluminium, steel, wooden panel, plastic panels. A continuously washable absorber was also developed, applicable in dusty situations such as certain factories [5].

A transparent micro-perforated absorber was also developed [6], based on Maa's pioneering work. Such transparent micro-perforated absorbers were successfully applied in the German Parliament House in Bonn, solved the focus problem while keeping 'political transparency'.

2.3 Cambridge

The author did his PhD from 1994 to 1996 at the University of Cambridge, supervised by Dr. Raf Orlowski. Seeing the practical challenges in designing the PA system for underground stations, especially for emergency, after the King's Cross fire in 1987, he developed the acoustic theory of long enclosures [7]. This was applied in collaboration with Arup acoustics in both the London Underground and the Hong Kong new Airport-Underground system.

He then stayed at the University of Cambridge as a College Research Fellow and Senior Research Associate until 1999, where he started the work on developing a prediction model for dining halls, inspired by a number of unintelligible conversations in Formal Halls [8]. He also expanded the acoustic theory of long enclosures into street canyons [9], with the demand at the time of predicting sound propagation in urban areas, as required by the noise mapping action under the EU Directive [1].

2.4 Sheffield

The author joined the University of Sheffield in 1999 as a lecturer and then became professor in 2003, to lead the Sheffield Acoustics Group, where a series of research projects were carried out. For example:

- The effects of urban morphology on the urban sound distribution were systemically examined, including a comparative study between typical UK and China urban structure [10].
- The acoustic characteristics of vegetation in the built environment were systemically examined, including sound absorption, sound scattering, sound transmission through single trees, hedges and forests, diffraction over green roofs, as well as fundamental research such as vibration of single leaves [11-14].
- A window system was invented which can reduce noise effectively and, in the meantime, allowing natural ventilation for comfort and daylighting, contributing to the overall sustainability [15]. The products have been successfully applied in Hong Kong.

3 SOUNDSCAPE

Soon after the author joined the University of Sheffield, he participated an EU project, where a large-scale field survey was carried out. It was revealed that in urban open public spaces, when the sound level is below about 65-70dBA, the sound level does not relate well to people's evaluation of sound quality, whereas social and contextual factors play a more dominant role [16]. This has been further demonstrated with more survey data in different context, and recently this is again shown in London: after the Covid-19 lock down, the noise level in London was reduced significantly, but the noise complaints increased almost three times, suggesting that reducing noise level would not always bring a better quality of life [17].

The above work [16] demonstrate the importance of considering soundscape, later defined by ISO [18] as 'acoustic environment as perceived or experienced and/or understood by a person or people, in context', and also marked a turning point of the author's research, from sound propagation focused to sound perception focused. This was also significantly influenced by the practical demand of creating quiet areas required by the EU Directive [1]. The author and the team systematically carried out a series of work on soundscape, in terms of understanding and exchanging, collecting and documenting, harmonising and standardizing, creating and designing, and outreaching [19-20]:

- Subjective/psychological evaluation of soundscape, considering various spaces/functions, sound sources, people, and various aspects such as attention, emotion, behaviour, social relations, meaning, mental health and valuation [21].
- Physiological evaluation of soundscape, considering a range of indicators including heart rate, respiratory rate and forehead EMG levels, and using a range of tools including fMRI techniques [22-23].
- Multi-sensory interactions, including sound-thermal, sound-smell, and sound-light [24-25].
- A framework of factors to be considered at the design stage [26].
- A taxonomy of sound sources, also considering categories of places [27].
- Soundscape (perception) modelling using artificial neural networks based on a large survey database [28].
- Design guidance at planning stage and detailed design stages, considering public participation [29-30].
- Tools for mapping, moving from noise mapping, to sound mapping, to soundscape (perception) mapping [31-33].
- Soundscape auralisation, considering the challenges of balancing perceptual accuracy and calculation speed [34-35].
- Soundscape management for new developments in terms of delivery sound environment [36].
- Establishment of soundscape database, considering questionnaire database, and aural-visual database.
- Application of the research results in practical projects, including traffic management/planning, guiding walking routine, sound source automatic identification, village preservation, and preservation of traditional sound marks [37].
- Impact on standards such as ISO standard on perceptual assessment of soundscape quality [18], and relevant policy.

4 SOUNDSCAPE INDICIES

Based on an ongoing ERC project, the current developments on establishing "soundscape indices" (SSID) are outlined, including: the SSID framework [38]; the SSID protocol for field soundscape survey, and the SSID protocol for laboratory soundscape listening tests [39-40]; establishment of the open SSID soundscape database including soundscape evaluation in different languages and cultures [41-42]; analysis of relationships among psychological, (psycho)acoustical, neural and physiological, and contextual factors, as well as their effects on soundscape descriptors [43-45]; an integrated soundscape prediction model [46]; and soundscapy, a soundscape analysis tool for soundscape designers [47]; and work towards a single soundscape index [48]. It is expected that SSID will adequately reflect levels of human comfort to integrate (and eventually replace) decibel-based metrics commonly used in existing (international) regulations, shifting the focus from noise control to a more holistic approach, and contributing to smart cities/buildings and digital engineering.

5 CONCLUDING REMARKS

Rooted from the classic theory of sound [49], the discipline of architectural and environmental acoustics has greatly expanded, towards a better quality of life, with a tendency from sound propagation focused work to integrating sound perception focused work.

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