Institution: University of Salford

Unit of Assessment: C16 Architecture, Built Environment and Planning

Title of case study: Applied Acoustics in the built environment and its broader uptake

1. Summary of the impact

Applied acoustics in the built environment and its broader uptake is focused on the development and commercial adoption of techniques and technologies resulting from research in applied acoustics, demonstrating the following impact:

- Developing standard methodologies in the areas of Rain Noise, Building Envelope design, Low Frequency Noise, Structure-borne Sound, Surface Acoustic Diffusion and Multi-porous materials;
- The adoption of standard practice in local and national government bodies in the UK and internationally, in test houses, the construction industry, consultancies and extending into automotive and aerospace industries;
- Commercial application of technologies deriving from the research in reducing environmental noise, improving environmental and performance acoustics, bringing economic and environmental benefit.

2. Underpinning research

The key researchers and positions they held at the institution at the time of the research are as follows: Dr Mags Adams (Lecturer 2004-2010, 2012 onwards), Professor Jamie Angus (Professor of Audio Technology, from 2001), Professor Trevor Cox, (Professor of Acoustic Engineering – 1989-93, 1995 onwards), Dr Andy Elliott (Research Fellow, from 2009), Professor Yiu Lam (Professor of Acoustics, from 1998), Professor Andy Moorhouse (Professor of Engineering Acoustics and Vibration, from 2004), Dr Dave Saunders (retired 2003), Dr Olga Umnova (Reader in Theoretical Acoustics, from 2004), Dr David Waddington (Reader in Environmental Acoustics, from 2000). The impact described in this case study is underpinned by research in applied acoustics in the built environment, including: rain noise, building envelope, low frequency sound, structure-borne sound, surface diffusion and porous materials, which are implemented in standard practice in the built environment sector with subsequent take up in the automotive, aerospace, mechanical and construction industries:

- **1994:** <u>Rain noise:</u> Saunders et al produced a novel method for characterisation of roof and roof light structures as sources of rain noise in buildings. A method is described for determining the sound power radiated from roof structures excited by water impact. A method of estimating the sound intensity level from natural rainfall is derived based upon the measured results and the characteristics of natural rainfall. **[1]**
- **1995:** <u>Building envelope:</u> Lam et al conducted fundamental research into the sound insulation characteristics of building envelope constructions. Lightweight profiled metal cladding systems generally have poor acoustic insulation characteristics, with traditional theories for evaluating noise transmission through building elements not applicable to double-skin profiled systems. A new method for predicting the sound reduction index (SRI) of commercial double-skin cladding systems was proposed and validated by measurement with implementation of the developed models funded by the industry trade association (Metal Cladding and Roofing Manufacturers Association). **[2]**
- **1989-onwards:** <u>Acoustic Diffusers</u>: Diffusers are used in spaces where acoustics is a critical requirement. They can be used to improve speech intelligibility in railway stations, theatres and teleconferencing rooms and are used in auditoria and studios where quality is important. Cox, Lam et al identified flaws in existing methods of characterising diffusion and proposed a new approach based on spatial auto-correlation functions, subsequently adopted as an international measurement standard and a method of obtaining a 'single figure of merit' for a diffuser which has facilitated new designs of diffusers used in rooms around the world **[3].** Angus proposed binary reflection amplitude grating which provides diffusion about an octave above the frequency whose wavelength is twice the size of the binary element. **[4]**
- **2004-present:** <u>Structure-borne sound:</u> Moorhouse, Elliott et al's research led to new

methods of characterising sources of structure-borne sound. A 'reception plate method' provides an engineering method for characterisation of equipment in buildings. **[5]** The equipment is installed on two test plates and the vibration of the plates is used to infer the 'source strength' of the machine and its structural dynamic properties. The single reception plate method was adopted as a European measurement standard, EN 15657-1:2009 for characterisation of structure borne sound sources on heavy floors. Moorhouse, Elliott et al subsequently developed the 'in situ blocked force' method where equipment cannot be decoupled from its surroundings for testing. This method leads to a more detailed description of the sound source than the reception plate method and has been widely adopted in the automotive industry and within aerospace. **[6]**

- **2009:** Low frequency noise: Moorhouse et al developed and applied a procedure for the assessment of low frequency noise (LFN) complaints **[7].** The development of the assessment method included laboratory tests addressing low frequency hearing threshold and the effect on acceptability of fluctuation, and field measurements complemented interview-based questionnaires. Environmental health departments then conducted a series of six trials with genuine "live" LFN complaints to test the procedure. **[8]**
- **2010:** Multi-scale porosity materials: Umnova has been conducting theoretical modelling of acoustic propagation in porous media since joining the Salford team in 2004. Nonlinear models were developed for high intensity sound and she and her co-workers reformulated the equivalent fluid model into the time domain. Collaboration with Cox led to investigation of some remarkable acoustic properties found in materials with two or more scales of porosity such as activated carbon. In the theory of sound propagation in multi-scale materials is extended to account for physical processes specific to very small pores, e.g. rarefaction and sorption effects previously unaccounted for in acoustic models. **[9]**

3. References to the research

Key outputs:

1. J. McLoughlin, D.J. Saunders, R.D. Ford. *Noise generated by simulated rainfall on profiled steel roof structures*. Applied Acoustics, Volume 42, Issue 3, 1994, p.239–255, DOI
2. Lam, Y. W. *Noise Transmission Through Profiled Metal Cladding, Part III: Double-Skin SRI Prediction*. Building Acoustics, Vol 2; Number 2, 1995, p.403-418 URL
3. Hargreaves, Tristan J and Cox, Trevor J and Lam, YW and D'Antonio, P, *Surface diffusion coefficients for room acoustics: Free-field measures*. Journal of the Acoustical Society of America 108, 2000, p1710, DOI
4. J. A. S. Angus, *Sound diffusers using reactive absorption grating,* proc. 98th convention Audio Eng.Soc., preprint 3953, 1995 Pdf available
5. B. M. Gibbs, N. Qi and A. T. Moorhouse, *A practical characterisation for vibro-acoustic sources in buildings*. Acta Acustica united with Acustica 93(1) 2007, p.84-93, URL
6. Moorhouse A T, Elliott, A S, Evans T A. *In situ measurement of the blocked force of structure-borne sound sources*. Journal of Sound and Vibration, 325 (4-5) 2009, p.679-685. DOI **(REF 2)**
7. Andy Moorhouse, Andy Elliott, Graham Eastwick, Tomos Evans, Andy Ryan, Sabine von Hunerbein, Valentin le Bescond, David Waddington. *Structure-borne sound and vibration from building-mounted wind turbines*. Environmental Research Letters, 6 035102, 2011, DOI **(REF 2)**
8. Moorhouse, A. T., Waddington, D. C. and Adams M. D. "Proposed criteria for the assessment of low frequency noise disturbance." Contract no NANR45, Defra London (2005).
9. Venegas, R, and Umnova, O. *Acoustical properties of double porosity granular materials*. J. Acoust. Soc. America (JASA) 130.5 (2011): 2765-2776. DOI **(REF 2)**

Key grants:

10. Noise transmission through profiled metal cladding systems. EPSRC (GR/H77088/01) 1992-1994, £59k.
11. Development of a diffusion coefficient for room acoustics. EPSRC, 1996-1999, £128k.
12. Volumetric Diffusers: A new paradigm for acoustic treatment. EPSRC, 2005-2008, £139k.

13. Structure-borne sound source model as a pre-processor for statistical energy analysis: SuBSS-SEA Pre-processor. EPSRC EP/D002109/1 2006-2009, £96k
14. IMP&CTS - in situ measurement method for prediction & characterisation and diagnostic testing of structure-borne sound. EPSRC (EP/G066582/1) 2009-2012, £253k
15. Research into Noise and Vibration from Building Mounted Micro-Turbines, joint-funded by Defra, DECC and DCLG, 2009-2010, £135k.
16. Time domain modelling of sound attenuation by porous materials. EPSRC, 2006-2009, £147k

4. Details of the impact

- Rain noise: McLoughlin and Saunders test method for rain noise formed the basis for an ISO standard (ISO 140-18: 2006); becoming the standard method worldwide for assessment of rain impact noise by roof and roof-light structures. Commercial test facilities specifically designed for this standard have been constructed in the UK and Germany.
- Government guidance on the acoustic design of educational buildings; BB93, which includes a methodology for predicting noise for different intensities of rainfall, forms part of UK Building Regulations, requiring specific design measures for rain noise assessed according to the standard, compulsory in all new schools built since 2003. Since 2012, rain noise assessment using ISO140-18:2006 has also been included in the 'Acoustic Performance Standards for the Priority Schools Building Programme'.
- Building envelope: Salford models for sound insulation of profiled metal cladding constructions were implemented into a PC based software package which was adopted by members of the Metal Cladding and Roofing Manufacturers Association (MCRMA) in 1995. Major UK construction and manufacturing companies have adopted the models. The software package is still in use by the majority of MCRMA members, a remarkable achievement given the rapid pace of developments in the industry and software over that period. Lam was commissioned to further update the models by the MCRMA in July 2013.
- Low frequency noise: Guidelines for assessment of low frequency noise have been adopted as a standard approach for low frequency noise complaints by Environmental Health Officers within UK local authority noise enforcement teams. The guidelines form a key part of the strategy for dealing with noise complaints within the Environment Agency, frequently cited in public enquiries. University of Salford training in the use of the procedure was commissioned by the Environment Agency in 2012 for their noise specialists.
- Structure-borne sound: A new reception plate method for characterisation of sources of structure-borne sound has been adopted as a European standard method for sound sources in buildings BS EN 15657-1:2009 *Acoustic properties of building elements and of buildings. Laboratory measurement of airborne and structure borne sound from building equipment*. This standard is called up by another standard EN12354-5: 2009 *Building acoustics — Estimation of acoustic performance of building from the performance of elements Part 5: Sounds levels due to the service equipment* for prediction of sound levels from services equipment.
- The Salford team was commissioned by Defra, CLG and DECC to employ the in-situ blocked force method in developing guidelines for prediction of structure-borne sound from building-mounted wind turbines for stimulating renewable energy generation by the removal of planning restrictions where possible. With usual methods for prediction and evaluation of noise from large and small wind turbines not applicable to structure-borne noise, the team was able to apply the blocked force successfully and establish the 'source strength' as a function of rotor speed for two models of micro wind turbines together with a prediction methodology. In 2009 a set of guidelines employing the method suitable for adoption by local authorities was drawn up and published on the Defra website, forming the basis of standard practice in the UK.
- Room Acoustic Diffusers: Cox's research has led both to an international measurement standard and to new designs of diffusers ISO 17497-2. As convener of ISO Working Group WG25 Cox contributed to the adoption of the internationally agreed measurement method

for diffusers, his diffuser designs can be found hundreds of rooms worldwide, examples include Sony M1 studios in New York, Cinema in Seattle and the Hummingbird Centre in Toronto. Cox worked as a consultant for the world's largest manufacturer of diffusing products, RPG Diffusor Systems Inc for over a decade.

- Angus' diffuser designs have been exploited commercially in the Binary Amplitude Diffusor/Absorber (BAD), which simultaneously provides uniform sound diffusion at high and mid band frequencies.
- Multi-scale porous materials: Umnova et al demonstrated the 'enhanced compliance', of multi-scale porous materials, specifically, activated carbon, to provide significant acoustic benefits, for example in sound insulation by making cavities appear acoustically larger than their physical size. The research outcomes led to the filing of two patents and formation of the spinout company CarbonAir in 2012 which has received two rounds of venture capital funding totalling £275k plus £55k other investment for exploitation. The company has secured licence contracts, including with a specialist manufacturer of acoustic treatment materials for studio and home theatre applications and a 12 year license agreement with a German Tier1 supplier to exploit multi-porous materials in car suspensions.

5. Sources to corroborate the impact

a) **Rain noise:** Example of industrial use of ISO140-18:2006: *http://www.kingspanpanels.nl/Kingspan/media/PDFs/NL/Producten/Acoustic-Performance-Guide-UK-06-05.pdf*

b) *Reference to rain noise standards in mandatory UK building guidance for schools: http://dera.ioe.ac.uk/15722/6/acoustic%20performance%20standards%20for%20the%20priority%20schools%20building%20programme%20september%202012.pdf*

c) **Building envelope modelling:** Use of models for prediction of sound insulation properties of metal cladding can be verified by MCRMA.

d) **Low frequency noise:**
   - Environment Agency
   - St Helens Borough Council Environmental Health.

e) **Structure-borne sound:** Test houses having constructed test rigs and participating in the round robin test of the methodology as in EN 15657-1:2009: Stuttgart FHS, PTB Braunschweig, CSTB Grenoble, University of Liverpool, University of Salford, KUL Leuven, University of Torino.

f) **Room Acoustic Diffusers:** RPG B.A.D Panel DIFFUSER: http://www.customaudiodesigns.co.uk/rpg-bad-panel-diffuser.htm

g) RPG Diffusor Systems

h) **Multi-porous materials:** CarbonAir