Institution: University of Edinburgh

Unit of Assessment: UoA 33: Music, Drama, Dance, Performing Arts, Film and Screen Studies

Title of case study: Physics-based audio in music composition and architectural acoustics

Period when the underpinning research was undertaken: 2005-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Stefan Bilbao	Professor of Acoustics and Audio Signal Processing	November 2005 – Present
Michele Ducceschi	Royal Society Newton International Fellow and Leverhulme Early Career Fellow	March 2015 – Present

Period when the claimed impact occurred: 2014-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Sound synthesis tools for musicians, developed through research into computer simulation-based sound synthesis and virtual acoustics at the Reid School of Music, have been taken up by contemporary music performers, leading to audio technology and software developments, innovative compositions and new potential for creative practice. This has resulted in 60 performances and gallery exhibitions in 19 countries, with more than 16,000 attendances. In addition, the tools were employed by artist Samson Young in an exhibition with a five-month run at the Guggenheim Museum in New York, which has a total annual visitor footfall of 1 million. The research has further underpinned a unique virtual architectural acoustics rendering system used by a building engineering firm in Oman.

2. Underpinning research

Research into physics-based sound synthesis and virtual acoustics has been carried out by the University of Edinburgh's Acoustics and Audio Group (AAG), a University-wide interdisciplinary group that is scientific in focus but led by the Reid School of Music. *Physics-based sound synthesis* refers to the generation of sound through computational algorithms, without the use of recorded material, greatly expanding the range of sound available to artists and musicians. *Virtual acoustics* refers to the emulation of the acoustics of an enclosed space, real or imagined. Traditional musical instruments, new virtual instrument designs, as well as the acoustics of concert halls – all can be emulated directly using the laws of physics.

Physics-based sound synthesis and virtual acoustics can both be thought of as direct analogues of the major advances in computer graphics rendering over the past 30 years, transposed to the world of sound. Such research is highly technological, but its ultimate aim is to produce a complete framework for the use of numeric simulation techniques to achieve very high-quality synthetic sound.

Research in this area by AAG has been ongoing since 2005. Early research (2006-2009) supported by EPSRC, the Leverhulme Trust, and the French ANR led to 50 publications and a monograph in 2009 [3.1]. This book was the first attempt, worldwide, to document strategies to improve the quality of digitally produced sound.

Further research between 2010 and 2016 put theory into practice. The focus turned to:

a. more realistic numerical models of real-world musical instruments
b. 3D wave-based modelling of architectural acoustics to render the effects of large environments
c. collaboration with artists to inform new virtual instrument designs, and investigate key questions of gesture and control
d. exploiting advances in parallel computing to accelerate computation times

The Next Generation Sound Synthesis (NESS) Project (Bilbao, ERC, EUR1,500,000 Euro, 2012-16) brought together an interdisciplinary team of twelve engineers and programmers from the AAG and Edinburgh Parallel Computing Centre. In addition to 84 peer-reviewed publications and five PhD theses [3.2], NESS yielded the world's first physics-based supercomputer sound synthesis and virtual acoustics system, accessible to creative artists remotely worldwide via a web interface. 15 musical works in a multichannel format suitable for immersive reproduction were created during 10 funded composer residencies in Edinburgh. A two-part article, describing all aspects of the NESS project appeared in the Computer Music Journal (MIT Press) in 2020 [3.3].

Ducceschi secured further funding (Newton International Fellowship, Royal Society 2015-17, GBP90,000, Leverhulme Early Career Fellowship, 2017-20, GBP99,000) [3.4], enabling expansion of the work into the area of real-time operation and leading to the formation of a company (Physical Audio) which has produced three products. Ducceschi was awarded an ERC grant in July 2020 (Starting Grant, EUR1,500,000, 2021-2026), to expand his work further into the domain of historical musical instrument emulation in conjunction with musical instrument museums at the UoE and elsewhere in Europe. Further ERC Proof of Concept funding (Bilbao, Wave-based Room Acoustics Modelling, EUR150,000, 2016-18) supported pre-commercialisation activities for the world's first wave-based virtual architectural acoustics rendering system [3.5, 3.6].

3. References to the research

3.1 **S. Bilbao**, *Numerical Sound Synthesis: Finite Difference Schemes and Simulation in Musical Acoustics*. John Wiley and Sons, Chichester, UK, 2009. 456 pp.
https://doi.org/10.1002/9780470749012
Single author monograph: ISBN: 978-0-470-51046-9

3.2 **S. Bilbao *et al.*,** The NESS Project. 89 published outputs, including: 24 peer-reviewed journal articles, 59 conference proceedings articles, 5 PhD theses, and a book chapter, 2012-2020. ERC-funded project, funded through open competition, with a success rate of 12%.
https://www.ness.music.ed.ac.uk /
https://web.archive.org/web/20201218004239/http://www.ness.music.ed.ac.uk/

3.3 **S. Bilbao *et al.*,** *Physical Modeling, Algorithms and Sound Synthesis: The NESS Project*, and *Large-scale Physical Modelling Synthesis, Parallel Computing and Musical Experimentation: The NESS Project in Practice,* Computer Music Journal, 43(2-3):15-47, 2019. 33 pp. (Peer-reviewed journal articles)
https://doi.org/10.1162/comj_a_00516 and
https://doi.org/10.1162/COMJ_a_00517

3.4 **M. Ducceschi and S. Bilbao**, *Conservative Finite Difference Time Domain Schemes for the Prestressed Timoshenko Beam Equations*, Wave Motion, 89:142-165, 2019. 24 pp. (Peer-reviewed journal article)
https://doi.org/10.1016/j.wavemoti.2019.03.006

3.5 **S. Bilbao and B. Hamilton**, *Higher-order Accurate Two-step Finite Difference Schemes for the Many-dimensional Wave Equation,* Journal of Computational Physics, 367:134-165, 2018. 32 pp. (Peer-reviewed journal article)
https://doi.org/10.1016/j.jcp.2018.04.012

3.6 **S. Bilbao,** *Modelling of Complex Geometries and Boundary Conditions in Finite Difference/Finite Volume Room Acoustics Simulation*, IEEE Transactions on Audio Speech and Language Processing, 21(7):1524-1533, 2013. 10 pp. (Peer-reviewed journal article)
https://doi.org/10.1109/TASL.2013.2256897

4. Details of the impact

The research has underpinned the creation of exhibitions and performances featuring entirely new forms of digital sound, thus extending the work of musicians, sound artists and curators. It has also enabled building engineers and reduced the cost of implementing architectural acoustic designs.

Creative practice

The NESS system has extended the potential for creative practice itself, through the introduction of entirely new virtual instruments, and enlarging widely the range of possibilities for digital sound.

The Hong Kong-based composer **Samson Young** used the NESS system to create an installation entitled *Possible Music #1,* exhibited at the Solomon R Guggenheim Museum in New York in the major exhibition *One Hand Clapping* (May to October 2018). In an interview for the Guggenheim blog, Young stated that using NESS "changed my idea" of how to create Possible Music #1 and praised the way NESS allows for a "*more 'real' form of sound synthesis than has existed before*" [5.1]. The Guggenheim's Associate Curator confirmed that the exhibition "*enabled us to explore new aspects of sound art and led to a better understanding of this unique art form*" [5.2].

Trevor Wishart, a leading international figure in electroacoustic music, during an Edinburgh residency in 2014, wrote an eight-channel piece entitled *Dithyramb: Kepler 63e*, which forms a section of his three-part major work *The Secret Resonance of Things.* Wishart used NESS to synthesise an experimental virtual brass instrument, which he then learned to play. He has explained how NESS enhanced his creative process: "*The process of search and discovery I usually use – experimenting with sound transformation of existing (recorded) sounds in order to discover new sounds that are both plausible and musically effective – carried over naturally, here, into the domain of pure synthesis*" [5.3].

Milan-based musician and producer **Gadi Sassoon** has made seven visits to Edinburgh since 2016, creating six pieces of multichannel music. Sassoon has worked extensively with both the offline NESS synthesis system and newer real-time products from Physical Audio. He wrote: "*Building music around the NESS sounds has led to the development of a new musical vocabulary, in terms of phrasing, harmony, arrangement and thematic development. In the realm of production of sound design, the introduction of these complex physical models into my workflow has pushed the envelope of how I approach dynamic processing, transient management and harmonic excitation: the richness of the sources [takes] texture and sonic sculpting to a new level*" [5.4].

Audio technology and software development

A further influence on creative practice relates to new possibilities for immersive sound. All music created on the NESS system is multichannel in nature; sounds from a single instrument can be performed using as many loudspeakers as desired. Though most works were created for 8 loudspeakers, **Gordon Delap**'s *Black Dog* was created in 32 channels as a work specially designed for the Immersion-Experience exhibition at the Société des Arts Technologiques in Montréal, Canada in 2016 and he continues to create work that is influenced by the project [5.5]. **Sassoon's** album *Multiverse*, created using the NESS system and released in 2020, was remixed in VR/AR format and the album is now being used as a demonstration showcasing immersive audio Atmos technology by Dolby Laboratories [5.6]. *Multiverse* charted at #1 on three charts – Ambient, Leftfield and Experimental Electronic – on Juno, the largest vinyl distributer in the world, in the week of its release [5.6].

Public performances and releases

The new technology has reached the public through more than 60 performances in 19 countries between 2014 and 2020.

Wishart's *The Secret Resonance of Things* has been performed 22 times internationally and featured in a series of sound installations at the Centro de Cultura Digital, Mexico City, which received 9,000 visitors from June to July 2015 [5.7]. *The Secret Resonance of Things* was released on CD by SoundOhm in 2017. Young's *Possible Music #1* at the Guggenheim was part of the *One Hand Clapping* exhibition which occupied two of the seven floors at the museum, which typically receives over 1m visitors annually [5.2]. A follow-up project, *Real Music*, was featured at the Talbot Rice Gallery at the University of Edinburgh (July to October 2019) as part of the Edinburgh Art Festival, with 11,978 attendees, the highest for any exhibition that year. The Gallery's Director noted that Young's work "*demonstrates how a highly specialised branch of physics can have a role in contemporary art* […] *with both parties helping to push each other's boundaries*" [5.8]. Delap's 16-channel installation *Ashes to Ashes* was exhibited at the Dublin Science Gallery in 2017 [5.5].

Architectural acoustics

The virtual and architectural acoustics system based on NESS has informed building designs in Oman. The system was used in the acoustic fitting of the British School Muscat (Oman) by Atlal Al Qurum acoustic consulting. The more accurate modelling of the building's acoustics enabled Atlal Al Qurum to address problems in the sound design prior to the construction stage; an acoustician confirmed that "*If we hadn't noticed the flutter echoes at the construction stage itself, fixing it would have a considerably higher overall cost implication for the client*" [5.9].

5. Sources to corroborate the impact

5.1 Guggenheim Checklist blog (18 May 2018)

5.2 Letter from Solomon R. Guggenheim Museum

5.3 Letter from Trevor Wishart

5.4 Letter from Gadi Sassoon

5.5 Letter from Gordon Delap and links to *Black Dog* and *Ashes to Ashes*

5.6 Letter from Dolby Laboratories, Inc. and chart information for Gadi Sassoon's *Multiverse*

5.7 Email from Centro de Cultura Digital

5.8 Attendance figures and article from the South China Morning Post re. *Real Music*, Talbot Rice Gallery, Edinburgh Art Festival 2019

5.9 Letter from SMT Acoustics | Atlal Al Qurum Trading and Contracting LLC