Institution: Nottingham Trent University (NTU)		
Unit of Assessment: B12 – Engineering		
Title of case study: The "Hive" installation, an immersive, multi-sensory experience that educates visitors about the vital role of bees in feeding the planet.		
Period when the underpinning research was undertaken: 2008 – 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Names:	**Roles:**	**Periods employed by submitting HEI:**
Martin Bencsik	Associate Professor	2004-present
Michael Newton	Associate Professor	1992-present
Period when the claimed impact occurred: 1 January 2014 to 31 December 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Artist Wolfgang Buttress and NTU scientists have co-created major immersive artworks, ever-changing through lighting and sound effects driven by machine learning algorithms analysing real-time honeybee colony activity. The gigantic 17 metre metal 'Hive' has brought honeybee conservation issues to prominence. It was conceived and constructed (for £6 million) for the 2015 World Expo in Milan, where it received 3.3 million visitors and 27 national and international industry awards. The 'Hive' is now a popular attraction at Royal Botanic Gardens Kew, experienced by 2.9 million people. Kew's annual report credited the opening of the 'Hive' as one of two developments that led to an 18.6% jump in visitor numbers. The sustained creative and scientific multi-disciplinary collaboration, originating with the 'Hive', has led to further immersive artworks and projects, including the Glastonbury 2019 'Beam' installation in the Greenpeace Field (100,000 visitors), 'BEES' at National Museums Liverpool, and [text removed for publication].

2. Underpinning research

The buzzing sound that emanates from a beehive is primarily a by-product of activity, it does not convey the inaudible vibrational hive communications. The latter normally take place locally and internally, carried via the wax within the comb or directly within bee to bee interactions. To record these meaningful signals inside a hive Associate Professor Martin Bencsik at NTU came up with the innovation of embedding ultra-sensitive accelerometers into honeybee hive frames to monitor honeybee colony activity. Exploiting his research background in Magnetic Resonance Imaging and numerical processing, and his academic expertise in Biometrics, Bencsik developed machine learning algorithms to extract features of interest from the vibrational measurements, revealing information about the status of the colony and sensing their intention to swarm (**R1**). Associate Professor Michael Newton, a chartered electrical engineer with an extensive background in measurement electronics at NTU, joined the research, leading on expanding and enhancing the electronics, hardware and experimental techniques and capabilities for the accelerometer-based hive vibrometry measurements.

By performing long term vibrometry recording and algorithmic analysis, alongside complementary video studies in observation hives, Bencsik and Newton have distinguished and identified vibrational signals uniquely related to specific physiological actions of the honeybees. Once these contributions to the honeybee's vibrational alphabet have been determined, software algorithms developed by Bencsik automatically scanned the data for the prevalence of these in closed hives. Bencsik and Newton demonstrated the use of these techniques to sense the brood cycle within a given frame (**R2**), to follow the onset of colony failure in the winter season, to automatically detect and count vibrational pulses of interest, including whooping signals, worker pipes, and the dorso-ventral abdominal vibration signal, important to bee keepers as it is widely accepted as a modulatory signal meaning "prepare for greater activity" (**R3**, **R4**). Using three-dimensional Fourier analysis over three specific time windows, this work culminated in the demonstration of using the history of occurrences of these signals to predict the colony's preparation for the swarming process (**R5**).

Led by Nottingham Trent University researchers Bencsik and Newton, the EU FP7 funded "Swarmonitor" project (2012-2015) (**G1**) undertook research into diagnostic monitoring of honeybee colonies. The research consortium included The Bee Farmers Association of the United

Kingdom, The Centre Apicole de Recherche et d'Information (Belgium), The European Professional Beekeepers Association (European Economic Interest Grouping representing Associations in 11 countries), The Institut National de la Recherche Agronomique (France), and companies Arnia (England), Capaz (Germany), and Szomel Services and Trade LLC (Hungary). Using highly sensitive vibration detectors the NTU-led researcher consortium decoded honeybee queens' "tooting and quacking" duets in the hive (**R5**). Previously assumed that these vibration signals where queens were talking to other queens, the research proved instead that this is communication between the queen and the worker bees, with tens of thousands of bees coordinating to release only one queen at a time. The research attracted worldwide media coverage from the BBC (UK, Science and Newsround, 16 Jun 2020), CBC Radio (As It Happens, Canada, 18 Jun 2020), 1 news TVNZ (New Zealand, 17 Jun 2020)

Research on the continuing 4-year EU H2020 funded B-GOOD project (**G2**) is creating dynamic learning and innovation systems to support beekeeper decision making, with the aim of enabling healthy and sustainable beekeeping across the whole EU. Bencsik and Newton lead work on developing innovative technologies for monitoring honeybee colonies.

3. References to the research

Underpinning research quality evidenced by rigorously externally peer reviewed outputs:

R1. Bencsik, M; Bencsik, J; Baxter, M; Lucian, A; Romieu, J; Millet, M. (2011). "Identification of the honey bee swarming process by analysing the time course of hive vibrations", *Computers and Electronics in Agriculture* 76: 44-50. http://doi.org/10.1016/j.compag.2011.01.004

R2. Bencsik, M; Le Conte, Y; Reyes, M; Pioz, M; Whittaker, D; Crauser, D; Delso, NS; Newton, MI. (2015). "Honeybee Colony Vibrational Measurements to Highlight the Brood Cycle", *PloS ONE* 10: Article Number e0141926. http://doi.org/10.1371/journal.pone.0141926

R3. Ramsey, M; Bencsik, M; Newton, MI. (2017). "Long-term trends in the honeybee 'whooping signal' revealed by automated detection", *PLoS ONE* 12: Article Number e0171162. http://doi.org/10.1371/journal.pone.0171162

R4. Ramsey, M; Bencsik, M; Newton, MI. (2018). "Extensive vibrational characterisation and long-term monitoring of honeybee dorso-ventral abdominal vibration signals", *Scientific Reports* **8**: 14571. https://doi.org/10.1038/s41598-018-32931-z

R5. Ramsey, M; Bencsik, M; Newton, MI; Reyes, M; Pioz, M; Crauser, D; Delso, NS; Le Conte, Y. (2020). "The prediction of swarming in honeybee colonies using vibrational spectra", *Scientific Reports* 10(1): 9798. https://doi.org/10.1038/s41598-020-66115-5

The high quality of the underpinning research is further indicated by the following major funding investments in the research and its dissemination:

G1. SWARMONITOR project, funded by European Union 7th Framework Programme, Grant FP7-SME-2-12-315146, 1 Nov 2012 to 31 Oct 2015. €1.42m total.

G2. B-GOOD project, funded by European Union H2020 Programme, Grant H2020-EU.3.2.1.1., 1 June 2019 to 31 May 2023. €7.96m total, €658k to NTU. 13 EU Countries.

4. Details of the impact

Impacts on creative practice and on the economic prosperity of the creative sector: **The 'Hive' installation, the focal structure of the UK Pavilion at the World Expo 2015**

• *NTU's Bee research stimulated new ways of thinking that has enhanced creative practice*:

The World Expo 2015 (Milan) theme "Feeding the Planet, Energy for Life" was announced in early 2014, and the UK Government's Trade and Investment Department (UKTI) ran a competition inviting tenders to design and build the UK's Expo Pavilion. Artist Wolfgang Buttress had the idea "*of taking a little piece of the British countryside over to Milan … I needed something to hang it on … So I thought of the bee*" (**S1**). Buttress found Bencsik's *Computers and Electronics in Agriculture* paper (**R1**), and they arranged to meet. It was the discussion of Bencsik's research and the visit to Bencsik's hives that crystallised the idea for the 'Hive' installation, Buttress acknowledged how "*We thought if the activity in the hives in Nottingham could transfer live to Milan … We'd have a sense of connection to nature and it would be a fluid thing. We wanted to create an emotional connection".* The artist's response to their first meeting set the scene for the profound and lasting

effect of this collaboration, *"It's incredible how it can take one thing in your life; this has changed my practice as an artist.*" (**S1**).

- *NTU's Bee research contributed to economic prosperity of the creative sector through the winning of a prestigious £6m contract to build the UK's Pavilion at the World Expo 2015*:

Buttress led a partnership bid for the UK Pavilion into the UKTI's Competition, including engineers Simmonds Studio and architects BDP. This bid featured Buttress and Bencsik's co-developed ideas, which were central to the bid providing an immersive experience with the 'Hive' installation as "*the focal point of the structure … a golden orb made of fine steel lattice … The 'Hive' will pulsate and buzz with the noise of a real bee colony … The honeycomb interior pays tribute to leading UK research breakthroughs … LED powered lights represent the recent hi-tech UK innovation of detecting and translating bee vibrations as a way of monitoring the health of the hive*" (**S2**). The bid won the competition and was commissioned to create the UK's Pavilion at the World Expo 2015, including a £6 million construction contract to British companies Stage One and RISE in April 2014 (**S2**).

- *Wolfgang Buttress's studio and NTU's Bee researchers pioneered the fusion of art, science, and technology, co-creating new multi-sensory forms of artistic expression in the 'Hive'*:

The UK Pavilion was an immersive, multi-sensory experience that highlights the decline of the world's bee population by focusing attention on the importance of pollination for food production. Of the 100 crop species that provide 90% of food worldwide, 70 are pollinated by bees. Light and sounds in the 'Hive' installation, as the focal point of the UK Pavilion, responded to movements in a real beehive with nearly 1,000 individually-addressable LED luminaires bringing the immense 40 tonne 17 metres high honeycomb inspired aluminium lattice structure to life. Bencsik's and Newton's live data and technology provided a three level immersive visitor experience: (1) On-beehive accelerometer voltage output was broadcast to the 'Hive' across internet replayed as sounds to the visitor; (2) The sounds, and colours of the LED luminaires, were modulated across the day controlled by a microprocessor driven by live beehive data; (3) Visitors could bite a wooden stick and feel the beehive vibrations via bone conduction transducers, simulating how bees (believed to be deaf) really communicate. Buttress commented, "*Dr Martin Bencsik from NTU was the primary collaborator with myself and my studio in conceiving the concept for the Hive and bringing it to realisation. He provided research in conjunction with the project, informing scientific content with rigour and accuracy to develop the experience, narrative and messaging for the installation*" (**S3**). Buttress further commented, "*My aspiration as an artist is to reconnect us to the natural world by creating memorable places and meaningful interactions. This has been achieved by carefully integrating and designing structural form with integrated lighting and soundscape systems. Bespoke, live scientific data-driven content creates responsive and fluid light and sound compositions. The resulting experience of the artwork feeds all the visitor's senses …The Hive reinterprets apiarian ecology as an immersive multisensory experience, leaving visitors with a lasting emotive response to the plight of the honeybee*" (**S3**).

- *The "Hive" reached 3.3 million visitors, and a worldwide audience of 450 million people*:

During the World Expo, 1 May 2015 to 31 October 2015, Prime Minister David Cameron, Italian Prime Minister Matteo Renzi and Irish President Michael Higgins were hosted at the UK Pavilion (**S4**). A UKTI press release stated, "*To reflect the Expo 2015 theme of "Feeding the Planet, Energy for Life" the UK Pavilion highlighted the ground breaking UK research in pollinators, principally the bee, and their role in the global food chain, including by renowned scientist Dr Martin Bencsik, who has been conducting pioneering research into bee vibration and communication patterns*" (**S5**). The press release quoted Lord Maude, Minister of State for Trade and Investment, who said, "*The UK Pavilion at the Milan World Expo 2015 was an outstanding success. It was visited by over 3.3 million people in just 6 months, with a further 450 million people viewing it across the world's media and online*" (**S5**).

- *The 'Hive' won critical acclaim and professional recognition with over 27 national and international industry awards* (**S3**)*, with citations praising the combination of art with science*:

The 2015 darc award for "Best landscape lighting project – high budget" (arc and darc magazine, peer-to-peer lighting design awards with 1,600 lighting design practices invited to select the

winner) citation specifically acknowledged how *"algorithms are used to convert the honey been vibrations into lighting effects*". The prestigious Blueprint award for "Best public use project with public funding" (Blueprint Magazine, 23 Oct 2015,) was presented to Wolfgang Buttress, BDP Architects, Tristan Simmonds Studio and Martin Bencsik. Judge Lyndon Neri, said, "*Staying true to its namesake, the project explores the metaphor on multiple levels - from space and experience, to form and graphics, to technology and science - a rigorous form of storytelling.*"

***Impact on public engagement with the plight of pollinators*: The 'Hive' at Royal Botanic Gardens, Kew, 'Beam' and Glastonbury festival**

• *2.9 million visitors (2016-2019) have experienced the 'Hive' at Kew, contributing to increased visitor numbers to Kew, with positive feedback prompting extension of the 'Hive's residency*:

The 'Hive' installation, complete with the immersive light and sound experience provided by Bencsik and Newton's research and technology, opened in Royal Botanic Gardens, Kew in June 2016 (**S5**). The 'Hive' was the first UK Pavilion to be reused and brought back to Britain after an Expo, as reported in the Guardian ("The sculpture controlled by bees", 17 Jun 2016). The cost to Kew for the Hive was in the region of [text removed for publication], including [text removed for publication] break-down and transport from Milan, new Kew site redesign of landscape and technology, new beehive connections locally, modifications and re-build cost (**S3**, sourced from project team Kew). Bencsik installed accelerometers into Kew's own hives to provide the vibrational data for their installation.

Kew's 2016/17 annual report acknowledged the return on this investment "*we have witnessed record visitor numbers following the installation of the Hive and the opening of the Great Broad Walk Borders*" (**S6**). This conclusion was echoed in the Association of Leading Visitor Attractions' announcement of its members' visitor figures for 2016, which stated that, "*Royal Botanic Gardens, Kew had an increase of 18.6% (13th place at 1,828,956) following the installation of The Hive from the UK Pavilion at the Milan Expo 2015 and the opening of their Great Broad Walk Borders*" (**S7**).

Originally planned as a 2-year temporary residence, subsequently Kew subsequently sought, and were unanimously granted (Decision on Application 18/1229/VRC, Richmond Borough Council, 28 Jun 2018), indefinite planning permission for the 'Hive' to have a permanent home at the Royal Botanic Gardens, Kew, UNESCO World Heritage site (**S3**).

Between 2016 and 2019, some 2.9 million people experienced the 'Hive' at Royal Botanic Garden, Kew's gardens, which equates to 45% of total number of daytime visitors to Kew gardens (**S8**). During the same period 18% of all visitors surveyed at Kew gardens nominated the 'Hive' as the most enjoyed feature of their visit (**S8**). The Visitor Insights Programme is Kew garden's continuous research sampling survey to measure and track the progress of visitor experience among day paying visitors and members. The survey provided quantitative evidence of the positive impact on the people that experienced the 'Hive', revealing that, across 2018 and 2019, 85% of Kew's 'Hive' visitors "*strongly or somewhat agreed with the statement that their visit to Kew helped them feel they or their children had learnt something*", compared with a lower figure of 76% amongst Kew's non-'Hive' visitors (**S8**). Visitor feedback demonstrated the success of Kew's rationale in engaging the public "*to explore the urgent issues we face in relation to pollinators, their intimate relationships with plants and their vital role in helping us feed a rapidly growing population*" (**S5**). The visitor comments included "*I also did not realize the amount of conservation research and work done at the Kew - The Hive in particular was a wonderful way to educate the public - I did not know different species of bees existed!*", "*The Hive was informative about bee behaviour*", and "*I also learnt more of how bees communicate with each other and what those sounds mean and sound like after visiting The Hive - fascinating!*" (**S8**).

• *Bee conservation has been promoted, reaching and influencing new diverse audiences through the Glastonbury festival*:

The Greenpeace Field at Glastonbury 2019 featured the 'Beam' installation. The artwork's audio-visual effects, co-created by Bencsik, included ever changing lighting and sound effects 24 hours a day using Bencsik's algorithms to relate the activity of the Cornish Black Bee colony living at Michael Eavis' Worthy Farm. This became a legacy bee conservation project post-Glastonbury, with festival goers using hand drills to create holes in the 'Beam' installation's 7,000 locally sourced

unprocessed Sitka Spruce posts trunks to entice solitary bees and other insects to make 'beam' their new home (**S9**). 'Beam' hosted more than 100,000 visitors over the five days of Glastonbury Festival 2019 according to *Creative Review* (**S10**).

Sustained impacts on creative practice and on the economic prosperity of the creative sector, in period and continuing: 'BEES' at National Museums Liverpool and [text removed for publication]

Since the original 'Hive' project, the successful creative-scientific collaboration between Buttress studios and Martin Bencsik and NTU, has continued to flourish and grow, with Benscik acting as the role of the Chief Scientist on numerous projects. The multi-disciplinary collaborative accomplishments of the 'Hive', and their co-creative concept of feeding live scientific data into artworks that never look the same twice, have reached into new realms such as solar flare activity in the 'Corona' sculpture (**S9**), and have tangibly provided significant further investment in the UK.

Buttress and Bencsik are part-way through designing a new multi-sensory exhibition for National Museums Liverpool called 'BEES'. The exhibition cost is [text removed for publication] and the Buttress studio design fees will total circa [text removed for publication], of which [text removed for publication] revenue has been earned thus far (**S3**). A further recent example of a Wolfgang Buttress and Bencsik collaboration project, following from the 'Hive' and related to indigenous bee species, [text removed for publication], "*has a construction cost of* [text removed for publication]*, with total UK Design fees in access of* [text removed for publication]*, of which* [text removed for publication] *revenue has already been earned*" (**S3**).

5. Sources to corroborate the impact (* participant in the process of impact delivery)

S1. Web-link: "An Interview with Wolfgang Buttress At Kew Gardens", Pendle Harte, Absolutely London, https://absolutely.london/kew-gardens-hive/
S2. Web-link: "British artist Wolfgang Buttress to design UK Pavilion at Milan Expo", https://www.gov.uk/government/news/british-artist-wolfgang-buttress-to-design-uk-pavilion-at-milan-expo, UK Trade and Investment, press release 18 May 2014
S3.* Testimonial letter: Wolfgang Buttress Studio.
S4. Web-link: "Gold award for British design and build at 2015 World Expo in Milan", https://www.gov.uk/government/news/gold-award-for-british-design-and-build-at-2015-world-expo-in-milan, UK Trade and Investment, press release 3 Nov 2015
S5. Web-link: "The Hive comes to Kew Gardens", UK Trade and Investment Press Release, 29 Jan 2016, https://www.gov.uk/government/news/the-hive-comes-to-kew-gardens
S6. Report in public domain: Royal Botanic Gardens, Kew Annual Report and Accounts for the year ended 31 March 2017, https://www.gov.uk/government/publications/royal-botanic-gardens-kew-annual-report-and-accounts-2016-to-2017
S7. Web-link: Association of Leading Visitor Attractions, press release 27 Mar 2017, https://www.alva.org.uk/details.cfm?p=453&codeid=789, and 2015-2019 Kew visitor figures which includes both daytime and evening visitors.
S8. Testimonial letter: Research Manager at Royal Botanic Gardens, Kew. This includes only daytime visitor data provided by Royal Botanical Garden Kew's Visitor Insights Programme.
S9.* Web-link: Wolfgang Buttress studios, "Hive", "Beam" and "Corona" works concepts, construction details, and team lists, http://www.wolfgangbuttress.com/works
S10. Web-link: "Greenpeace UK, BEAM Pavilion, Honourable Mention: Design, Installations and Exhibitions" https://www.creativereview.co.uk/greenpeace-uk-beam-pavilion/