Institution: University of the West of Scotland		
Unit of Assessment: 12: Engineering		
Title of case study: Advancing Health, Economic and Environmental Benefits through Smart Built Asset Management (S-BAM)		
Period when the underpinning research was undertaken: 2013 - 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**:
Des Gibson	Professor	2014 - 2020
Dr Ashwini Konanahalli	Reader	2016 - 2020
Zeeshan Pervez	Professor	2013 - 2020
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Dr Shigeng Song	Reader	2012 - 2020
Period when the claimed impact occurred: 2014 - 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

With many governments around the world now setting stringent targets for decarbonisation, achieving energy efficiency, promoting environmental wellbeing and, sustainability of the built environment have never been more pressing. Tapping into this global opportunity through the development of the world's lowest power consumption combined temperature/ humidity/ carbon dioxide sensing solution and the pioneering work around strategic asset management, Smart Built Asset Management (S-BAM) research at UWS has: (1) improved the sustainability of buildings by demonstrating energy savings (25%) whilst assuring proper indoor air quality (IAQ), and devising a cost-effective sensor deployment strategy (2) provided its project partners with the next generation of highly innovative autonomous sensors utilised in buildings worldwide and (3) achieved strong industrial and international engagement, paving the way for development of global Facilities Management (FM) technology standards.

2. Underpinning research

Context

The underpinning S-BAM research was initiated by various projects undertaken by Construction Innovation and Built Environment Research (CIBER) group and the Institute of Thin Films Sensors and Imaging (ITFSI), supported by the Artificial Intelligence, Visual Communications and Networks (AVCN) centre. Leveraging technological advancements and adopting a strategic approach, the subject area was tackled from various perspectives, in that ITFSI focussed on design, development and commercialisation of autonomous sensing infrastructure whereas, CIBER Team prioritised strategic asset management.

Key findings

Focusing on S-BAM sensing infrastructure, ITFSI team secured **[3.A]** a research-intensive project with industry partners Gas Sensing Solutions and Sharp Laboratories of Europe, for developing the world's lowest power consumption sensor, addressing specific market requirements for monitoring and control of combined temperature/humidity/CO_2 in buildings. Deployment of CO_2 sensors helps with two main aspects of monitoring building performance i.e. facilitates optimal control of indoor air quality (IAQ) and reduces energy usage in heating, ventilating and air conditioning (HVAC) systems. Through demand control ventilation (DCV), CO_2 sensors, integrated with temperature and humidity sensing, allow the HVAC system to adjust the amount of outside air coming in based on the levels of CO_2 in the building i.e. CO_2 concentration control can be set to suit the level of people occupancy.

It has been established that IAQ is a critical factor for effective management of facilities (including well-being, comfort, and enhancing productivity among building occupants). CO_2 gas is safe in low concentrations but higher variations in the gas composition (prolonged exposure at moderate levels typically >5,000 ppm) can lead to a range of health-related problems such as sick building syndrome and fatigue-like symptoms. Given that most greenhouse gases are indirect CO_2 emis-

sions from electricity use in buildings, deployment of such energy-efficient and low-carbon solutions is becoming an important part of the international effort to tackle global warming and reduction of building carbon footprint.

Since built assets produce a wealth of data from their very inception through to their use and reuse, specifically live data from sensors, CIBER focussed on strategic asset management. In collaboration with **Whole-life Consultants Ltd**, the feasibility of a fully functional and commercially exploitable Asset Management Tool - Built Asset Lifecycle Intelligence (BALI) was completed **[3.B].** The Alpha version of web-based BALI tested synchronous communication and user-centric rather than traditional model-centric collaboration between the built environment professionals, and provided evidence for informed decision-making. Additionally **[3.C]**, the influential **Royal Institution of Chartered Surveyors (RICS)** Commissioned Report published and led by UWS with co-authors from the Universities of Leicester, Leeds and West of England, and several major industrial participants was the first to generate empirical data and scientific evidence from real-life best-practice case studies that actually demonstrated the business value of 'Big Data applications' in Facilities Management (FM).

Prior work conducted by Principal Investigator **[3.A]** and Gas Sensing Solutions reported on specific development and productionisation of a fully integrated CO_2, temperature, and humidity sensor for "fit and forget" deployment in buildings capable of running on an AA battery for a ten-year period. Building on this foundational work, **[3.A]** developed an autonomous ultra-low power battery operated wireless multi-parameter (CO_2 + Temperature + Humidity) sensing solution. **[3.F]** is the patent associated with this sensor. This sensor not only represents a less expensive route to flexible deployment (as opposed to hardwired devices), it takes a fraction of the time to stabilise, self-calibrate and continually correct for drift with time making it the ideal choice for the built environment sector. It can either be powered by batteries or self-powered by solar cells. **[3.1]** describes the development of indoor photovoltaic (PV) energy harvesting power module (IPEHPM) for powering an Internet of Things (IoT) sensor node containing a low-power CO_2 sensor for automatic DCV in buildings – it achieved 88.7% average storage efficiency with indoor lighting level of 200 lux. Further, **[3.2, 3.3]** were among the first to propose a novel approach to random neural network (RNN) based occupancy estimator for controlling the HVAC system through DCV. **[3.3]** not only evidenced 27.12% less energy usage with smart controllers as compared to simple rule-based controllers, but also established 88% accuracy of hybrid RNN occupancy estimator.

Based on combined research efforts, an extensive and comprehensive qualitative and quantitative dataset, **[3.4]** presented a methodological framework outlining the key strategies used by forward looking FM organisations to comprehensively engage, integrate and understand the ever-growing FM Big Data (BD). **[3.5]** moved on to empirically categorise the drivers and challenges associated with BD implementation and synthesise findings into best practice guidance on how to implement such initiatives in live business environments.

Collectively, this underpinning research has thus provided a framework for developing and offering S-BAM 'as service' to organisations through Knowledge Transfer Partnerships (KTPs).

3. References to the research

3.1 Yue, X., Kauer, M., Bellanger, M., Beard, O., Brownlow, M., **Gibson, D.,** Clark, C., MacGregor, C. and **Song, S.,** (2017) Development of an Indoor Photovoltaic Energy Harvesting Module for Autonomous Sensors in Building Air Quality Applications. *IEEE Internet of Things Journal*, 4(6): 2092-2103. https://doi.org/10.1109/JIOT.2017.2754981

3.2 Javed, A., Larijani, H., Ahmadinia, A., Emmanuel, R., **Gibson, D.,** and Clark, C., (2015) Experimental testing of a random neural network smart controller using a single zone test chamber. *IET Networks*, 4(6): 350-358. https://doi.org/10.1049/iet-net.2015.0020

3.3 Javed, A., Larijani, H., Ahmadinia, A., Emmanuel, R., Mannion, M. and **Gibson, D.,** (2017) Design and Implementation of a Cloud Enabled Random Neural Network-Based Decentralized

Smart Controller With Intelligent Sensor Nodes for HVAC. *IEEE Internet of Things Journal*, 4(2): 393-403. https://doi.org/10.1109/JIOT.2016.2627403

3.4 Konanahalli, A., Oyedele, L., Marinelli, M. and Selim, G., (2018) *Big data: a new revolution in the UK facilities management sector*. [online] London: Royal Institution of Chartered Surveyors (RICS). Available at: https://www.rics.org/globalassets/rics-website/media/knowledge/research/research-reports/big-data-a-new-revolution-in-the-uk-fm-sector-rics.pdf

3.5 Konanahalli, A., Marinelli, M. and Oyedele, L., (2020) Drivers and Challenges Associated With the Implementation of Big Data Within U.K. Facilities Management Sector: An Exploratory Factor Analysis Approach. *IEEE Transactions on Engineering Management*, Ahead of Print: 1-14. https://doi.org/10.1109/TEM.2019.2959914

Grants

3.A *Gibson, D.,* *Self-powering gas and environment wireless sensor platform for fixed or portable deployment in building automation, horticulture and medical applications*, InnovateUK, April 2015 to December 2016, GBP265,462.

3.B *Radosavljevic, M.,* *BALI – Built Asset Lifecycle Intelligence: Feasibility study to develop a digital ecosystem for management of built assets through life*, InnovateUK, September 2015 to August 2016 GBP85,769.

3.C Konanahalli*, A.,* *Big Data: A new revolution in UK Facilities Management Sector*. Royal Institution of Chartered Surveyors (RICS) Commissioned report, August 2016 to October 2018, GBP9,998

3.D Konanahalli*, A.*, Pervez, Z., Ramzan, N., Gibson, D., Knowledge Transfer Partnership, "*Smart Facilities Management Framework Development"*. InnovateUK, August 2019 to July 2022, GBP192,270.

3.E Pervez, Z., Konanahalli*. A.,* Ramzan, N., Knowledge Transfer Partnership, *"Developing a predictive analytics framework for condensation and mould detection",* Innovate UK, August 2019 to July 2021, GBP123,502.

PATENT

3.F Gibson, D., Waddell, E., (2018) *"Miniaturised infrared spectrometer optical configuration",* application number GB1702480.3. Available at: https://www.ipo.gov.uk/p-ipsum/Case/ApplicationNumber/GB1702480.3

4. Details of the impact

Process of research leading to the impact: Fundamental research into S-BAM comprises multi-directional efforts by ITFSI and CIBER to address the enormously complex needs within the built environment. These continue to include publishing in leading journals, as well as a commissioned report and protecting generated intellectual property through a patent **[3.F].** The resulting knowledge, combined with AVCN's real-time operational data analytics capability, facilitated Knowledge Transfer awards in rapid succession **[3.D, 3.E]**. With a wide range of beneficiaries at regional, national and international levels, the reach and significance of S-BAM research impact can be categorised as:

Enhanced energy efficiency, cost-effectiveness, and indoor environment quality of buildings: Buildings are responsible for at least 40% of the world's total energy consumption and, energy intensive HVAC systems account for approximately 40%-60% of a building's total energy

consumption. Underpinning research **[3.A, 3.3],** has demonstrated that deployment of CO_2 sensors along with DCV application for HVAC systems is a cost-effective and energy-efficient strategy, leading to 25% of energy savings in buildings, whilst achieving IAQ levels suited to comfort and productivity of occupants. These results lend strong support to notable Green building certification initiatives (Green Building Council's Leadership in Energy and Environmental Design (LEED), Building Research Establishment's Environmental Assessment Method (BREEAM) and, Green Star), and more specifically to international standards (American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Green Standard 189.1 and, the European standard EN 13779) that recommend the use of DCV for reduction in energy usage whilst promoting healthy indoor environments. This backing from green building schemes and scientific research demonstrating relationship between IAQ monitoring, occupant productivity and wellbeing is significantly driving adoption of advanced CO_2 sensors in commercial buildings.

With a best-in-class performance of +/- 30ppm resolution with < 3mJ per measurement, this versatile sensor researched by ITFSI addresses the technical and economical requirement for stability, sensitivity and, self-calibration to implement DCV. Additionally, it provides a lower cost route to flexible deployment compared to hardwired alternatives, as they obviate the need to run wiring for power supply. This proprietary wireless sensor is ideal for retrofit market as it eliminates 80% of the installation cost and achieves overall cost reductions of 50% (compared to wired systems). Powered from an energy harvesting source supplemented with supercapacitors for energy storage, and low-cost thin film based rechargeable batteries; the battery usage is fully optimised.

Commercialisation of autonomous sensor: Gas Sensing Solution Ltd. (GSS), a leading supplier of solid-state CO_2 gas sensors and key collaborator of **[3.A]** reported that the **Innovate UK project** provided the foundational research to develop next-generation, mid-IR sensors used in gas sensing products across the world. Their customer base which includes world-leading sensor companies such as **Draeger** and **Thermokon (Germany)**, **Flamefast (UK)**, **Emerson (US),** have evidenced a dramatic reduction in cost of ownership (due to increased time between power charging events). This generation of products are a significant revenue generator for **GSS**, with sales now approaching **100k+ units in more than 46 countries [5.1].**

According to the CEO of GSS:
"A strong technology roadmap is essential to allow GSS to remain at the forefront of the gas sensing market and we see collaboration such as on this project (Ref:102156) as an essential element in helping to make the next product development breakthrough…… It has allowed GSS to sustain a competitive advantage in markets especially where power is at a premium".

Continuing from the success of **InnovateUK Project [3.A]** and further development work, from 2017 **Lightricity (Spin-out company from Sharp Research Labs Europe)** has moved up the value chain from being a supplier of photovoltaic (PV) devices to developing their very own PV-powered wireless sensing solutions, communication devices and sub-systems.

According to the Co-founder of Lightricity:
"Lightricity's sensing devices are currently being trialled by several multi-national system integrators for large-scale deployment in public sector and commercial buildings in the UK and internationally, with demand anticipated to reach 900,000 units p.a. by 2026."

Currently, 98% of batteries bought in the UK end up in landfill where they release harmful heavy metals into the environment, causing soil contamination and water pollution. Lightricity's energy harvesting module for autonomous sensors (6 times more efficient per area than existing products) offers a scalable and sustainable solution to this perpetual issue, in that it completely avoids the use of disposable batteries; not only offering a fit-and-forget operation but - most importantly - reducing maintenance costs **[5.2].**

Collaborative industrial engagement: Collectively, ITFSI, CIBER and AVCN teams have engaged in applied research through KTPs. The longstanding relationship established between **Key**

FM and UWS in **[3.C]** was the catalyst for **[3.D]** to develop Smart Facilities Management capabilities and offer data-based services. To date, the team have built an analytics-driven normalisation engine to prepare the diverse FM data sources to work in a holistic fashion, in line with the future business value proposition **[5.3]**. Additionally, **[3.E]** KTP project is focusing on monitoring indoor air quality and mould development in social housing schemes **[5.4]**.

Development of standards, international training and policy: Leadership role of KeyFM in the development of FM as a global discipline, and **ISO 41001 standard**, **[3.D]** was developed as a use case to inform the development of a **new standards on FM technology (ISO 410016)**. As a result, the **[3.D]** Principal Investigator, **an inducted member** of the British Standards Institute **FMW/001/0-/10** UK mirror panel informing the work of the International Organization for Standardization **ISO/TC 267 WG 6**, is currently co-developing a Technical Report titled "Technology in Facility Management – Scope, key concepts and benefits". It aims to increase technology literacy and aid development of FM technology strategy to support core business.

Drawing on the cutting-edge S-BAM research, various international training and knowledge exchange initiatives were undertaken. Since UWS is the official training partner for China with accreditation from China's State Administration for Foreign Expert Affairs (SAFEA), collectively AVCN and CIBER members with KTP partners delivered training for the leadership cohort from the **Zhejiang Science and Technology Cooperation Center (ZSTCC)** on *"Emerging applications of Artificial Intelligence, S-BAM best practice case-studies and, Introduction to ISO 41001"*. Following this, a Memorandum of Understanding was signed with ZSTCC to further a 'Talent cultivation and professional training programme' and establish a **pioneering Zhejiang-UWS Innovation Base** in Zhejiang Province and Scotland **[5.6].**

To support the UK and Scottish Governments' Building Information Modelling (BIM) mandate UWS has also participated in the development of the 'BIM Competency Framework' (2018) spearheaded by Construction Scotland Innovation Centre (CSIC), Scottish Futures Trust (SFT) and Construction Industry Training Board (CITB) to detail the knowledge requirements and learning for BIM training. This report has set a minimum standard to support both academia and industry to align the curriculum, training, and upskilling digital collaboration **[5.7].**

5. Sources to corroborate the impact

5.1 Testimonial from Gas Sensing Solutions Ltd. (GSS)

5.2 Testimonial from Lightricity Limited

5.3 Testimonial from Key Facilities Management (UK) Ltd. and Convenor of ISO/ TC 267 W6.

5.4 Testimonial from BRS Technology Limited.

5.5 Testimonial from Wholelife Consultants UK limited.

5.6 Memorandum of Understanding with Zhejiang Provincial Science and Technology Cooperation Center.

5.7 Bush, R. and Robinson, M. (2018) Developing a BIM Competency Framework: Research and key principles. Scottish Futures Trust. https://www.scottishfuturestrust.org.uk/storage/uploads/bimcompetencyframeworkresearchjul18.pdf