Impact case study (REF3)

REF2021

Institution: Cardiff University

Unit of Assessment: Engineering (12)

Title of case study: Leveraging Building Information Modelling (BIM) to improve environmental performance of our buildings and infrastructure

Period when the underpinning research was undertaken: 2010 – 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:
Yacine Rezgui	Professor	01/07/2008 – present
Thomas Beach	Reader	04/10/2010 – present
Ioan Petri	Lecturer	10/03/2011 – present
Wanqing Zhao	Research Fellow	01/04/2014 – 31/12/2018

Period when the claimed impact occurred: 1/8/2013 – 31/12/2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact (indicative maximum 100 words)

Energy use and CO_2 emissions in buildings often exceed design predictions by up to 50%, leading to environmental concerns and economic losses. Cardiff research into Building Information Modelling (BIM) leverages dynamic and complex multi-disciplinary engineering models to develop methods for modelling to reduce this performance gap. These Cardiff innovations were applied across the built environment and adopted by industrial partners such as Schneider Electric, Dŵr Cymru Welsh Water, Costain, and Highways England changing practice, improving efficiency of energy usage and increasing profits. The research also impacted policy and practice by leading and supporting the widespread adoption of BIM by organisations across the construction sector long before mandatory adoption.

2. Underpinning research (indicative maximum 500 words)

Decarbonizing the built environment and reducing the energy performance gap (the difference between predicted and actual energy usage in a building's operation) requires a complex series of variables to be understood and modelled for each use case. Rezgui is the leader of the BRE Trust-funded Centre for Sustainable Engineering, which led research projects into: 1) improving the performance of buildings through modelling and optimisation; 2) broader work on meeting the challenges facing widespread industry adoption of these techniques; as well as 3) novel applications of the same techniques beyond buildings, including within waterway control projects.

2.1 Closing the performance gap in building energy optimisation

Building Information Modelling (BIM) is the generation and management of digital representations of physical and functional characteristics of a building. Within the EU-funded SPORTE2 project **[G3.1]**, Cardiff research developed a BIM-oriented methodology which combined three interactive modules to produce a reliable, flexible, and (near) real-time solution to complex energy optimisation problems; this maximised outcomes, including energy and carbon reductions, while minimising optimisation time-to-complete. The Cardiff method produced a substantial reduction in energy wastage and highlighted the need for inter-disciplinary thinking and reliable, up-to-date datasets when implementing this optimisation method on an actual building **[3.1]**.

The Cardiff team also developed a semantic mapping process to determine the most sensitive variables to reduce the energy gap for any given building, with (near) real-time capability. To do so, a novel BIM-based semantic method using deep learning (i.e. a combination of artificial neural network and genetic algorithms) generated energy saving rules which factor in multiple objectives and constraints. Validation results suggested an average 25% energy reduction while continuing to meet occupants' comfort conditions **[3.2]**. An efficient least angle regression algorithm was developed to produce a model selection which delivered both model

accuracy and solution convergence, while demonstrating greater efficiency of resource use and speed than alternative methods **[3.3]**.

2.2 Encouraging BIM adoption

As highlighted in the SPORTE2 research, the full advantages of BIM can only be achieved where high levels of trust and data-sharing exist amongst project teams. Institutional reticence to do so was slowing down BIM adoption by key industry stakeholders. Under the Innovate UK Clouds-for-Coordination (C4C) project **[G3.2]**, of which Cardiff was the sole academic partner, the Cardiff team proposed a federated BIM data-sharing ecosystem to support multi-disciplinary project collaboration, where project stakeholders were given federal control over part of the BIM model relevant to their work. This federated model incorporated the concept of 'Issue Status' for physical documents, in which documents are given statuses to indicate what they can be reliably used for, and therefore what the issuing party accepts responsibility and/or liability for **[3.4]**. A validation case study undertaken using real construction data from a UK highways project demonstrated that both the federated BIM overlay, and its underpinning process and governance approach, could alleviate ownership and trust concerns between stakeholders on large projects **[3.5]**.

2.3 Optimisation methodologies for water

Cardiff's research was further expanded to explore unusual applications of the same concepts, such as in the water utility field. As part of the EU WISDOM project **[G3.3]**, the Cardiff team proposed a systematic optimisation methodology for (near) real-time operation of water networks with a similar approach to that taken in building energy optimisation; specifically, where an operational strategy can be dynamically updated using a model-based predictive control scheme with minimal human intervention. The research showed, through simulation results based on a hydraulic model provided by Dŵr Cymru Welsh Water, that the proposed methodology can greatly reduce the network operational cost. It also suggested that 23.7% cost savings can be achieved compared with the water utility's current operational strategy if adaptive pricing is adopted for all the pumping stations **[3.6]**.

3. References to the research (indicative maximum of six references)

[3.1] Petri, I, Li, H, **Rezgui, Y**, Chunfeng, Y, Yuce, B, Bejay, J. 2014. A modular optimization model for reducing energy consumption in large scale building facilities. *Renewable and Sustainable Energy Reviews* 38, pp. 990-1002. (10.1016/j.rser.2014.07.044)

[3.2] Yuce, B. and **Rezgui, Y**. 2015. An ANN-GA semantic rule-based system to reduce the gap between predicted and actual energy consumption in buildings. *IEEE Transactions on Automation Science and Engineering*, pp. 1-13. (10.1109/TASE.2015.2490141)

[3.3] Zhao, W., **Beach, T**. and **Rezgui, Y**. 2017. Efficient least angle regression for identification of linear-in-the-parameters models. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 473(2198), article number: 20160775. (10.1098/rspa.2016.0775)

[3.4] Petri, I., **Beach, T**., Rana, O.F. and **Rezgui, Y**., 2017. Coordinating multi-site construction projects using federated clouds. *Automation in Construction* 83, pp.273-284. (10.1016/j.autcon.2017.08.011)

[3.5] Beach, T, Ioan, P, **Rezgui, Y**, Omer, R 2017. Management of collaborative BIM data by the Federation of Distributed Models. *Journal of Computing in Civil Engineering* 31(4), article number: 4017009. (10.1061/(ASCE)CP.1943-5487.0000657)

[3.6] Zhao, W., **Beach, T**. and **Rezgui, Y**. 2018. A systematic mixed-integer differential evolution approach for water network operational optimisation. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 474(2217). (10.1098/rspa.2017.0879)

Selected grants:
[G3.1] SPORTE2, European Commission (ID: 260124), €4.66M, Sept 2010 – Aug 2014. Cardiff PI: **Rezgui, Y**.
[G3.2] Clouds-for-Coordination, UKRI (ID: 101417), £532,765, Jan 2014 – Dec 2015. Led by BRE; Co-PI: **Rezgui, Y**. and **Beach, T**.
[G3.3] WISDOM, European Commission (ID: 619795), €4.4M, Feb 2014 – Jan 2017, Cardiff PI: **Rezgui, Y**.

4. Details of the impact (indicative maximum 750 words)

Cardiff's Building Information Modelling (BIM) research resulted in impact in two primary areas: 1) new products and services, as well as change to practice, with associated economic benefits for industry partners; and 2) broader change to policy at European and UK levels, affecting the whole BIM sector.

4.1 Impacts on industry partners

a. Schneider Electric

From 2012 to 2014, Cardiff collaborated with Schneider Electric on the SPORTE2 EU project, with Cardiff leading the Work Package on cloud-based energy optimisation measures **[5.1]**. Schneider Electric incorporated Cardiff research from the project into their Internet-of-Things-driven integrated hardware and software architecture 'EcoStruxure'. Cardiff optimisation measures were incorporated within two of seven EcoStruxure domains, 'Building' and 'Power', which are designed to reduce operating expenses and energy expenditure through active energy control and monitoring in the cloud.

Schneider Electric confirmed that in Italy alone, the new measures supported the business case to invest €0.5M specifically to commercialise the software in the Italian market in 2016 **[5.1]**. Since then, Ecostruxure has matured into a pivotal technology for Schneider globally, who estimate that 15% of their total revenue was generated by EcoStruxure in 2019 (approximately €4.08BN of a total €27.2BN revenue) **[5.2]**.

Since commercial release Ecostruxure has been extensively deployed worldwide, generating financial savings and economic benefit through reduced energy wastage. Clients who have benefitted from Ecostruxure 'Building' domain include the following, as outlined in **[5.3]**:

- Hilton Hotels (worldwide) reported average 3% savings per year through energy procurement and cost avoidance;

- Melbourne Cricket Ground, the 10th largest stadium in the world (100,000 capacity) identified waste and reported financial and energy savings benefits as a result;

- Huashan Hospital, North China, experienced 18% reduction in energy consumption and 20% increase in management efficiency, as well as implementing proactive power safety measures with the functionality available;

- Marriot Hotels deployed the architecture in China to produce energy savings of 10-15%;

- Shanghai Metro, which serves 10 million passengers a day, reported greater safety, efficiency, stability of service and comfort for passengers;

- Shedd Aquarium, USA, utilised Ecostruxure to meet target energy savings of 50% across 480,000 square feet of building space.

Donato Zangani, RINA Consulting and coordinator for the SPORTE2 project concluded: "*In sum, the SPORTE2 project, and the optimization capability implemented by Cardiff University, has opened a new pathway towards smart industries and the emerging world-wide market where Schneider Electric SA is successfully trading*" **[5.4]**.

b. Smart water meter strategy for Dŵr Cymru Welsh Water

Cardiff collaborated with Dŵr Cymru Welsh Water (DCWW) as part of the EU-funded WISDOM Project between 2014 and 2018. In April 2017, 250 water meters were installed in residential homes, and Cardiff led the measurement and analysis of the resulting data. WISDOM aimed to develop an information and communication technology platform to allow water companies to better manage data from water networks.

Tony Harrington, Director of Environment for DCWW confirmed that "*This work, under the leadership of Cardiff University, has helped us to shape our future strategy in adopting smart technology for household metering*" **[5.5]**. DCWW stated that the research had led to three outcomes that directly influenced DCWW strategy including **[5.5]**:

- better calculations of household water, informing future strategy for the optimum resolution and intervals for recording water usage;

- clearer understanding of the "*implications and responsibilities for a water company*" when implementing such a programme, shaping DCWW's project management, governance, and customer communication strategies;

- improved stakeholder engagement plans in pursuit of greater acceptance, and wider implementation of smart meters.

The outcomes of these insights have now been included in DCWW's five-year Water Asset Management Plan for 2020-2025, which includes plans for scaling up the use of smart meters across Wales **[5.5]**.

c. Costain

Costain are one of the UK's leading smart infrastructure companies, with over 3,400 employees across the UK and a turnover of £1.16BN in 2019. Between January 2014 and 2016, Costain were industry partners on the collaborative Clouds-for-Coordination (C4C) Project, led by Cardiff, which developed a system that allowed multiple partners within a construction project to effectively share BIM information (see Section 2.2). Costain applied the developed system into their Highways England BIM Level 2 projects, including the £174M project to build a new 6.5km dual carriageway between Knutsford and Bowden, and the £88.4M project to upgrade 5km of the A160 from single to dual carriageway, including a new bridge **[5.6]**. Recognising the value of Cardiff's research, David Owens from Costain's Digital Transformation Group noted that "*For Costain, the solution implemented by Cardiff University has informed the digital transformation of the business*" **[5.6]**.

Costain are now working towards the next generation of BIM, known as Level 3, characterised by greater openness and collaboration within a single shared project view, and in which digitisation is embedded within the lifecycle of a project. Following from the C4C collaboration, Costain have "*changed [their] BIM level 3 agenda*" and noted that the resulting "*competitive advantage has allowed Costain to be involved in a £3.8bn super sewer project*" through which Costain have trained 2,000 construction industry leaders from across the UK in how to bring latest technology to the sector **[5.6]**.

4.2 Changing policy and practice across the European BIM sector

a. Influencing European policy

The European Construction Technology Platform (ECTP) is an industry-led stakeholder group representing over 150 members, recognised by the European Commission as advisors for driving innovation, knowledge transfer, and European competitiveness. Dr Alain Zarli, the Secretary General of the ECTP highlighted that Cardiff's BIM research informed *"policy and practice"* **[5.7]** across Europe as follows:

- The ECTP cited Cardiff projects that have "*provided actionable insights to the EU to boost energy performance of buildings and improve the existing building stock*", specifically informing the 2018 amendment to the EU Energy Performance in Building Directive (EPBD 2018/844/EU). The Secretary General commented that Cardiff's

research projects have also informed the ECTP's own "*challenges and priorities*" in forming their strategic research and innovation agenda over the next few years.

- The ECTP reported that Rezgui's research was "*instrumental*" in their discussions with the European Commission Directorate General Energy on the EU's Green Deal, an ambitious legislative roadmap for net zero carbon emissions across the EU by 2050, decoupling resource use from economic activity, while avoiding disadvantage to citizens.

- The Secretary General also noted that practitioners have benefitted from the research through training offered by Cardiff which is "*playing a driving role in the digital transformation of the Construction industry in Europe*".

The ECTP stated that Rezgui's research projects *"are informing the research agenda of the European Commission, in particular in the context of the upcoming Horizon Europe programme"* and added that: "*all your [Regzui's] projects have had a significant impact on the Construction research and practice landscape in Europe in the area of BIM and the digitization of the construction sector*" **[5.7]**.

b. Influencing UK adoption of BIM

The expertise developed through the research also led to a number of integrations with industry and government which have impacted broader areas of policy within the UK:

- **Building Research Establishment (BRE)** – Nick Tune, former Director of BRE Wales and BRE Director of Leadership of Digital Product Creation, highlighted the role of Rezgui's research in driving BIM adoption: "*Your perspective on BIM, well before the UK Government BIM strategy, was enlightening and helped me in my capacity of BRE Group Director to engage BRE into the BIM adoption journey in the UK and internationally*" **[5.8]**. As a result of this enhanced perspective, Tune led the drive for open BIM in the UK and played a leading role in establishing the BIM agenda in the UK alongside fellow colleagues from BuildingSMART UK and beyond **[5.8]**.

- **Highways England** – Cardiff University leads the D-COM network, a body which reports on the UK's current state of automated regulatory compliance, and how the sector can best achieve and take advantage of digitisation of built environment regulations, enabled by BIM. The Cardiff team utilises their expertise to lead the network and advise on best practice. Steve Davey, Highways England's Head of Technical Standards confirmed that between 2019 - 2020 the reports produced by D-COM **enabled an additional £2.5M in funding** for Highways England, supporting further digitisation of the Design Manual for Roads and Bridges, as well as the Specification for Highway Works **[5.9]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Testimonial: Andrea Natale, Business Development Manager at Schneider Electric

[5.2] *Schneider Electric Full Year 2019 Results* (February 2020)

[5.3] Compilation of EcoStruxure case studies

[5.4] Testimonial: Donato Zangani, SPORTE2 Coordinator and RINA Consulting R&D Manager

[5.5] Testimonial: Tony Harrington, Director of Environment, Dŵr Cmyru Welsh Water

[5.6] Testimonial: David Owens, Digital Transformation Group, Costain

[5.7] Testimonial: Dr Alain Zarli, Secretary General of the European Construction Technology Platform (ECTP)

[5.8] Testimonial: Nick Tune, former Director of BRE Wales

[5.9] Testimonial: Steve Davy, Head of Technical Standards, Highways England