Institution: University of Northumbria at Newcastle		
Unit of Assessment: 12 (Engineering)		
Title of case study: Transforming the global construction sector through Building Information Modelling		
Period when the underpinning research was undertaken: 2012 – 2019		
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:
David Greenwood	Professor	01/09/1980 – present
Mohamad Kassem	Professor	01/10/2016 – present
Claudio Benghi	Senior Lecturer	01/08/2009 – present
Barry Gledson	Senior Lecturer	01/11/2010 – present
Jane Matthews	Senior Lecturer	01/08/2009 – 03/05/2013
Period when the claimed impact occurred: August 2013 – December 2020		
Is this case study continued from a case study submitted in 2014? No		

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

Building Information Modelling (BIM) can transform the ways buildings and infrastructure are designed, constructed, operated, and maintained, and is fundamental to multiple government strategies for the digital transformation of their respective construction sectors. Research into BIM technologies and processes at Northumbria University had economic impact through the award-winning spin-out BIM Academy Enterprises Ltd, that generated GBP5,400,000 in earnings (August 2013 – December 2020), improved productivity, and transformed working practices for 80+ UK and international clients. More than 5,000 construction professionals in the UK, China, and Africa were upskilled. Policies for the digital transformation of 11 countries were directly improved and funding for their implementation was unlocked, including EUR22,240,000 in Spain (December 2019) and CAD10,000,000 in Canada (October 2020).

2. Underpinning research (indicative maximum 500 words)

Building Information Modelling (BIM) represents a systemic change to practices within the construction sector as it has brought a fundamental shift in the technologies, processes, and skills required to design, construct, and manage built assets. BIM benefits can extend over the entire life cycle of built assets; from improved quality and predictability of design, through increased confidence in construction schedules and budgets, to enhanced sustainability of physical assets. It can also contribute to delivering built assets of all types, including infrastructure such as road systems, stadiums, and power stations. In 2011, the UK Government announced that BIM would become mandatory on all centrally-procured construction projects from 2016. However, there were still important challenges and barriers to the successful adoption of BIM. These were addressed by a systematic research agenda at Northumbria, based around three challenges:

i)   BIM technologies and systems must give project teams the ability to exchange design information and data in an interoperable way [**R1**] and perform rapid value engineering (e.g., sustainability analysis) at early design stages [**R2**]

ii) BIM technologies and processes must enable the transfer of information and data across design, through construction, to handover and in-use phases while minimising both loss and redundancy [**R3**, **R6**]

iii) Successful adoption of BIM at project, organisation [**R5**], and market levels [**R4**] requires actionable findings, and there is an urgent need to upgrade skills and practices [**R4**, **R5**]

The first challenge was addressed by investigating the ability of 14 commonly used proprietary BIM technologies to exchange data (geometry and metadata) using the Industry Foundation Classes (IFC) schema (an international standard for open BIM). This showed that current commercial BIM technologies, whilst technically capable of providing support for the required geometric representations, are constrained from doing so by their interfaces for IFC geometric conversion [**R1**]. This exposed the potential risk of hindering collaboration among project teams using IFC as a means for data exchange [**R1**]. Further research investigated how BIM technologies can perform rapid sustainability analyses at the early design stages by exploiting

the high-value data exchange that occurs within a collaborative project team [**R2**]. As part of the 'Build Qatar Live' 2012 competition for a full feasibility study for a Qatar 'National Architecture Museum', Northumbria researchers demonstrated the ability of BIM technologies to integrate key sustainability criteria and perform calculations for the proposed design options. Research [**R2**] highlighted the benefits of streamlined and structured data exchange at the early design stage. The team was awarded Overall Winner of the 2012 Build Qatar Live international competition.

Northumbria researchers addressed the second challenge by studying the process of transferring information into the in-use phase of built assets [**R3**]. This research addressed the uncertainty as to the extent to which industry-wide standards and technologies can convey the data required for the in-use phase and enable its handover from earlier design and construction phases. The results identified gaps in existing standards that were not able to convey all the required information for facilities management. This led to a new approach that enables owners to define information requirements for asset management, the project's supply chain to deliver this information, and for it to be checked before handover to the in-use phase [**R3**].

The arrival of Kassem in 2016 with expertise in 'macro BIM' policies for the digital transformation of construction sectors at country/market level, was key in addressing the third challenge. In collaboration with Australian colleague Succar, Kassem developed models for assessing the following at market/country level: 1) diffusion of BIM systems and processes amongst adopters; 2) availability and maturity of key components for digital transformation; 3) the dynamics of BIM diffusion/spread; 4) actions available to policy makers to accelerate digital transformation; 5) stakeholder responsibilities and their sharing. These models, unique on the world stage, were successfully tested and validated with 101 industry experts from 21 countries [**R4**].

The adoption of BIM was also investigated at organisation and project level by Gledson and Greenwood [**R5**]. They focused on 4DBIM (3D+Time), a process by which shared data models enable the dynamic visualisation of the construction process over time to identify challenges, minimise risk and optimise progress. After investigating the effectiveness of 4DBIM adoption in UK organisations and projects, they concluded that system compatibility and safe trialling were critical [**R5**]. These findings were instrumental in identifying the need for and informing the development of 'Virtual Project' (VP), a transformative resource for upskilling the industry.

The increased use of BIM models and the data within them has posed a challenge of processing capacity, particularly on major assets and megaprojects. Northumbria's team collaborated with Tsinghua University (China) to develop new optimisation techniques for storage, transmission, and viewing of mechanical, electrical, and plumbing models [**R6**]. In tests on a 9,000 m^2 station on Guangzhou metro, data volume was reduced by over 80% with no loss of fidelity [**R6**].

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

R1. Lockley*, S., **David Greenwood**, **Jane Matthews**, and **Claudio Benghi** (**2013**) 'Constraints in authoring BIM components for optimal data reuse and interoperability: results of some initial tests' *International Journal of 3-D Information Modelling (IJ3DIM)* **2** (1): 29-44 https://doi.org/10.4018/ij3dim.2013010104

R2. Alwan*, Z., **David Greenwood**, and **Barry Gledson** (**2015**) 'Rapid LEED evaluation performed with BIM based sustainability analysis on a virtual construction project' *Construction Innovation* **15** (2): 134-150 https://doi.org/10.1108/CI-01-2014-0002

R3. Patacas**, J., Dawood**, N., **David Greenwood**, and **Mohamad Kassem** (**2016**) 'Supporting building owners and facility managers in the validation and visualisation of asset information models (AIM) through open standards and open technologies' *Journal of Information Technology in Construction* (ITcon) **21**: 434–455 https://www.itcon.org/2016/27 Available on request

R4. **Mohamad Kassem** and Succar**, B. (**2017**) 'Macro BIM adoption: Comparative market analysis' *Automation in Construction* **81**: 286-299 https://doi.org/10.1016/j.autcon.2017.04.005

R5. **Barry Gledson** and **David Greenwood** (**2017**) 'The adoption of 4D BIM in the UK construction industry: An Innovation diffusion approach' *Engineering, Construction and Architectural Management* **24** (6): 950-967 https://doi.org/10.1108/ECAM-03-2016-0066

R6.	Hu**, Z.Z., Yuan**, S., **Claudio Benghi**, Zhang**, J.P., Zhang***, X.Y., Li***, D., and **Mohamad Kassem** (**2019**) 'Geometric optimization of building information models in MEP projects: Algorithms and techniques for improving storage, transmission and display' *Automation in Construction* **107**: 1-16 https://doi.org/10.1016/j.autcon.2019.102941

*Internal Northumbria co-authors: Lockley, Alwan (UoA13) ****External university co-authors:** Patacas, Dawood (Teesside University); Succar (University of Technology Sydney); Hu, Yuan, J.P. Zhang (Tsinghua University); *****Industry co-authors:** X.Y. Zhang, Li (CBIM Beijing Co., Ltd)

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

Northumbria University's research has had global impact in terms of (i) economic and productivity impact through the award-winning BIM Academy Enterprises Ltd (BIMAE); (ii) upskilling, by creating research-led training resources for construction professionals, and (iii) policy impact by influencing the BIM policies, funding, and roadmaps of 11 countries.

4.1 Economic and productivity impact

The research-led consultancy company, BIM Academy Enterprises Ltd (BIMAE) is a 2013 spin-out based on Northumbria's BIM research. Northumbria's BIM research (i.e., the body of work from Section 2) continuously feeds into BIMAE and underpins its work. Graham Kelly, Director of BIMAE, stated: *'We have continuously relied on Northumbria's research [he explicitly cites **R2**, **R3**, **R5**] in our projects, enabling BIMAE to maintain competitive edge in the sector… Expertise developed in research projects, and through Northumbria's continuous research and innovation, has enabled BIMAE to win business that would otherwise be unachievable. Between 2013 and 2020, BIMAE became a centre of excellence for digital construction and transformation and has generated over GBP5,400,000 in earnings [August 2013 – Dec 2020]… we employ 10 permanent staff members [10 FTE] and are one of the world's leading strategic consultants in the digital transformation of the built environment. We operate globally, with a client list of over 50 companies in the UK and over 30 overseas'* [**E1**]. BIMAE projects include:

- In Hong Kong, the Hospital Authority (HKHA) commissioned BIMAE to undertake a feasibility study on the business value of BIM and identify adoption timescales. As a result, HKHA mandated BIM on its entire HKD20,000,000,000 programme [**E2**, p41].
- Sydney Opera House (Australia) – BIMAE *'combined technical excellence and industry experience to create a comprehensive technical specification for our [Sydney Opera House's] bespoke BIM for FM [Facilities Management] solution'* [**E2**, p48], enabling a more efficient operation and maintenance of this iconic building.
- Forest City (Malaysia) – BIMAE created a digital Asset Information Model (AIM) for the Landmark Building in this USD100,000,000,000 development. Head of Digital Engineering Centre stated: *'We invited BIM Academy to help us because we know they successfully scoped and delivered the Sydney Opera House BIM4FM project. This practical expertise is what we needed to facilitate our AIM project delivery at Forest City'* [**E2**, p50].
- BMW Group – BIMAE acted as client advisor in BMW's EUR1,000,000,000 and 500,000 m^2 plant in Hungary, overseeing the development of a comprehensive 3D digital information model that was used to analyse, optimise and coordinate the design. The client stated: *'[BIMAE] has the academic aspect and the connection to an established design practice… which is a great combination'* [**E2**, p54].

BIMAE's achievements were recognised with the 2017 *Times Higher Education* award for the UK's 'Most Innovative Collaboration between Business and Academia'.

4.2 Upskilling construction personnel

Northumbria's BIM research [**R5**] underpinned bespoke training which regularly accompanies BIM Academy's consultancy commissions, an example being a national programme for major contractor Sir Robert McAlpine [**E2**, p30]. Northumbria's research was also fundamental in creating 'Virtual Project' (VP), a transformative resource for upskilling the industry. VP was developed with digital training provider White Frog Publishing Ltd, whose Managing Director stated: '*We developed VP from early in 2015, along with, and based upon the work of Prof. David Greenwood and others from Northumbria University's BIM Academy… VP has become a key part of our offering in the UK and globally and the role played by the research and innovation*

work of Northumbria University was fundamental in its development. We estimate that VP has been responsible for upskilling over 5,000 construction practitioners and professionals worldwide and has contributed around GBP250,000 of increased turnover in the 5 years that we have been offering it' [**E3**]. Those who have been upskilled include more than 1,500 in the UK (including at NHS, Balfour Beatty, Wates, Kier, Arup), 2,000 in China, and 1,000 in Africa (including staff from Kenya's Julius Nyerere Hydro Electric Dam, South Africa's Public Works Department, and Ethiopia's Construction Project Management Institute) [**E3**].

4.3 Global public policy impact
Kassem's macro BIM research [**R4**] has directly shaped the national policies, skills development, and digital transformation roadmaps of construction sectors in 11 countries:

Canada: In 2018, Groupe BIM du Québec (a non-governmental organisation working with the Ministry of Economy and Innovation Québec) used [**R4**] to formulate policy recommendations for the digital roadmap for the Québec construction sector, resulting in the 'Quebec Construction 4.0 Initiative' (IQC 4.0). [text removed for publication] *'Prof Kassem's research enabled us to develop a systematic approach to BIM adoption with actionable advice, helping to secure support of the Québec Ministry of Economy and Innovation, local construction associations and the Institute of Digital Governance, to directly influence the adoption of these policy actions … Kassem played a key role in helping IQC 4.0 to guarantee the initial **CAD10,000,000** [October 2020] in funding from the Québec Government for a 5-year programme to evaluate digital skills/competencies… This funding has enabled IQC4.0 to help the Québec construction industry improve their competency of digital project delivery. This has led to a reduced risk for our public sector clients by enabling them to appoint qualified firms, capable of effectively delivering public projects and ensuring value for money… SQI [a government agency overseeing Québec's construction sector] announced their intention to mandate BIM on all of its projects over CAD5,000,000 within the next 3 years'* [**E4**].

Spain: In 2018, buildingSMART Spain (who represent stakeholders in the Spanish construction sector) used [**R4**] to produce a national Macro BIM Adoption report assessing progress of BIM implementation [**E5**, p1] and a follow-up report in 2019 [**E5**, p17]. These reports were used as evidence to make policy recommendations about adopting emerging international standards, and for the BIM methodology to be incorporated in all public procurement. buildingSMART Spain [text removed for publication] stated: *'Since the publication of our recommendations and our role in pursuing the public sector to adopt them, a significant progress has been made… Projects requiring BIM has grown in the first half of 2020 by 60% compared to the same period of 2019, and the total amount of these projects arises EUR815,000,000 in the last 2 years'* [**E6**]. The Government has invested EUR500,000 in training and guidelines to support BIM skills [**E6**]. He added: *'since the publication of our recommendations, the Spanish Government increased its support for R&D projects in cooperation with the private sector. An increase of 10% in funding related R&D projects occurred in 2018 and 2019, amounting to a total increase of **EUR22,240,000** [December 2019]. [Northumbria's research was] crucial to both identify the necessary policy actions for digital transformation and enable the changes described above within the public and private sector'* [**E6**].

Ireland*:* Between 2016 and 2018, Ireland's Construction IT Alliance (CitA - a network of the Irish engineering and construction sector) used [**R4**] to inform the Irish National BIM Council's 'Roadmap to Digital Transition for Ireland's Construction Industry 2018-2021' [**E7**]. This sector is worth EUR20,000,000,000 annually, and as of 2020, the Roadmap has been downloaded 3,200 times. The Roadmap set industrial performance goals, outlined a high-level plan of strategic initiatives to assist the industry to build digital capability, and was designed to secure funding for digital transition development in Ireland. CitA's [text removed for publication] stated: *'[Kassem's research] was instrumental in guiding the design of this national strategy, and his models for assessing BIM maturity are used throughout the document… [The roadmap] has had a direct impact on increasing both government and industry investments in digitalisation and digital skills… I would like to acknowledge the critical importance of the influence of Prof. Kassem's work in helping to shape the strategic direction of Irelands Roadmap'* [**E7**, p1-2].

Mexico, and seven countries from Latin America and Caribbean region (Argentina, Brazil, Chile, Uruguay, Colombia, Costa Rica, Peru): In 2018, Kassem was appointed to investigate the status of BIM in Mexico and develop policy recommendations for its adoption. This led to a strategic report for Mexico's Ministry of Finance and Public Credit (SHCP), which utilised the report to develop Mexico's national policy for BIM adoption. SHCP's [text removed for publication] explained: '*Kassem's work influenced directly our national policy to BIM adoption and helped us to identify the underpinning enablers…These are essential contributions to help Mexico establish the foundation for achieving information transparency, time and cost improvements on public infrastructure projects. We consider his report essential for progressing Mexico's BIM maturity… the work has had also an impact on investments in digitalisation and digital skills within the public and private sector*' [**E8**].

Northumbria's research has been also used to harmonise BIM implementation efforts between countries. In 2019 Kassem was part of a team appointed by the Inter-American Development Bank (IADB) to investigate BIM across five countries (Mexico, Argentina, Brazil, Chile, Uruguay) and to develop policy recommendations for a coordinated approach across these countries. This led to a report entitled 'BIM in Latin America and the Caribbean: Macro Adoption Report'. SHCP's [text removed for publication] explained: *'[The report] provided key recommendations for policy makers about how to ensure successful digital transformation and called up collective action and regional collaboration in encouraging BIM adoption, preventing effort duplication, enabling knowledge-sharing, and accelerating digital transformation*' [**E8**]. The final report was utilised by IADB to establish an international cooperation project to harmonise digital transformation efforts of construction sectors across the Latin America and Caribbean region and is now adopted by seven further countries in the region including Argentina, Brazil, Chile, Uruguay, Colombia, Costa Rica, and Peru [**E9**].

5. Sources to corroborate the impact (indicative maximum of 10 references)		
Ref.	**Source of corroboration**	**Link to claimed impact**
1	Testimonial - Graham Kelly, Director of BIM Academy Enterprises Ltd	Corroborates the role of Northumbria's research in BIMAE projects and economic impact on the company
E2	BIMAE capability statement (2020)	Corroborates BIMAE worked on identified projects, and provides upskilling in BIM
E3	Testimonial - Peter Routledge, Managing Director, White Frog Publishing	Corroborates Northumbria's research underpinned the training product and that over 5,000 practitioners have been upskilled
E4	Testimonial - [text removed for publication] Groupe BIM du Québec and Director, Initiative Québécoise pour la construction 4.0, Canada	Corroborates Northumbria's influence on national strategy of BIM adoption within the country and unlocked investment in digital transformation
E5	Two buildingSMART reports from Spain, 2018 and 2019	Corroborates that Northumbria has directly influenced national strategy of BIM adoption within the country
6	Testimonial - [text removed for publication] buildingSMART Spain	Corroborates impact on Spain, increased BIM adoption and BIM government investment
E7	Compilation including a testimonial from [text removed for publication] CiTA, and a digital roadmap report from Ireland's National BIM Council	Corroborates Northumbria's influence on national BIM strategy and investment in BIM in Ireland
E8	Testimonial - [text removed for publication] Ministry of Finance and Public Credit, Mexico	Corroborates direct influence on national strategy of BIM within Mexico, and across seven other countries within Latin America
E9	Inter-American Development Bank, *BIM in Latin America and the Caribbean, Macro Adoption Report* April 2019	Corroborates Northumbria has directly influenced national strategies of five countries in Latin America and Caribbean and improved international cooperation on BIM