

Institution: Ulster University		
Unit of Assessment: Art and Design: History, Practice and Theory (32)		
Title of case study: Visual and Behavioural Digital Realism: The Human Machine Nexus		
Period when the underpinning research was undertaken: 2002 - 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:
Dr Justin Magee	Senior Lecturer in Product Design	1999 - present
Prof Greg Maguire	Professor of Animation	2010 - present
Mr Terry Quigley	Lecturer in Creative Technologies and Design	2007 - present
Period when the claimed impact occurred: 2016 - 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact Ulster's award-winning research impacts across Animation, Heavy Engineering and Medical sectors, through digitally realistic 3D design and technology, impacting: 1. The economy by directly securing GBP7,733,777 industry collaborative R&D investment, and influence on unlocking Government funding of GBP4,900,000 for the engineering sector and approximately GBP7,000,000 for the Animation sector, and venture capital funding of USD3,000,000 for medical printing, shaping the sectors. 2. Direct sales growth in Animation (GBP1,153,777) and Medical Printing (GBP251,000) and contribution to Engineering sales growth (GBP23,237,000). 3. Employment generation of 49 high skilled creativity-led jobs (headcount: 49; FTEs: 39). 4. Transformation of pre-operative patient care through surgical effectiveness and patient communication (approximately 60 case studies). 5. Practitioners and professional services developing national case studies, establishing excellence in the region by applying best practice across all three sectors.		
2. Underpinning research Collectively this research explores quantifiable animated motion and the visceral believability of human anatomy. While Magee and Quigley developed precise internal mechanical behaviour, Maguire's focus was on muscular patterns. Quigley was a Research Assistant on both research grants. Early developments of these independent tracks of research were collectively showcased at Imagine Create (2009), later Magee and Maguire were involved with securing the AHRC funded Future Screens NI (FSNI) Creative Industries Cluster (I1). Magee's original research initially funded by the Department of Arts Culture and Leisure (DCAL, 2002) Creativity Seed Award (GBP44,933) explored non-invasive imaging of the spine using photography of external anatomy. Working with 2 Research Assistants, the need to develop precision modelling and reproduction research methods was identified. Furthered by his PhD study into '3D digital modelling of Spinal Posture' (2004-2009), he advanced 3D digital realism knowledge for human skeletal anatomy (R1) and human skeleton machine behaviour (R2). In parallel, he secured the RCUK funded Digital Human project (2006-2012) employing 2 Academic Fellows (G1) expanding insights beyond the quantitative spine to the head and hands with several publications stimulating scientific debate within HSC R&D Recognised Research Groups. This quantifiable and photoreal research informed a sophisticated approach for machine-based kinematics software in two industry sectors, collaborating on research projects with CDE Global and Axial3D. Design methodologies were applied through the Double Diamond process framework, a range of Design Thinking techniques and empathic design methods (G2, G3).		

For CDE Global Ltd **R1** and **R2** informed believable machinery behaviour within heavy engineering (**R3** with Quigley). As the world leader of equipment for wet-processed mined aggregates, their machines range in size from that of a van to a house and vastly larger modular structures. The cost and logistics of physical installation at international expos is substantial and sometimes non-viable. Research embedding user empathy and immersive interaction informed 3D digital libraries of full-scale machines, with realistic behaviour, that were quantifiably developed from FEA analysis (**G2/A1**). It was discovered that customer acceptance was achievable for large scale equipment using immersive digital realism creating a believable sense of presence. A national case study was published by the National Centre for Universities and Business and recognised by the Times Higher Education (**R3/A2**).

For Axial3D, **R1** and **R2** informed the research methodology, digital anatomy visualisation, machine learning and interaction experience strategies for 3D medical printing, producing digitally twinned anatomy software (Axial3D, **R4**). Axial3D provides pre-operative models for surgeons to help plan procedures more effectively. While approximately 3 million potential cases per year could benefit from 3D printing, there is approximately 3,000 years' worth of manual labour required to address this demand. We discovered that realistic anatomical rendering, refined user workflows and clear GUI systems developed into individual software applications (the *Axial3D Insight* software suite, **R4/A3**) significantly accelerated surgical decision making and improved patient communication (**G3**).

Maguire's early research which proposed a *High-level Facial Animation Interface* (Maguire, 2008) has been significantly advanced by developing new 4D facial animation systems, which challenge the 'uncanny valley' boundaries in digital human realism. It was accelerated through his spin out company HUMAIN (2016), attracted the prestigious 'Audience of the Future' Research funding (**I1**) and significant commercial investment (**GBP1,812,524**). He led the Ulster University collaborative research agreement with Dr Erika Rosenberg (2017), world-renowned expert in the Facial Action Coding System (FACS), developing the seminal work of Dr Paul Ekman. Maguire's research extends insights through applied technological methods with visually discernible facial movement, hitherto unidentified (**R5**). HUMAIN captured Rosenberg posing all FACS Action Units (AUs) and their common combinations (140 scans) as 4D data and as very high-resolution photogrammetry. These unique databases of authentic, robust and peer reviewed datasets underpin HUMAIN's face retargeting software. For the first time, blended motion between AUs were defined.

3. References to the research Outputs can be provided by Ulster University on request.

R1. **Magee, J., McClelland, B., & Winder, J. (2012).** Current issues with standards in the measurement and documentation of human skeletal anatomy. *Journal of Anatomy*, 221(3), 240-251. DOI: 10.1111/j.1469-7580.2012.01535.x

R2. **Magee, J (2015),** Three-Dimensional Digital Modelling of Human Spine Anthropometrics and Kinematics from Meta-analysis. How Relevant is Existing Anatomical Research? *Journal of Spine* vol 4, no. 1, pp. 1-7. DOI: 10.4172/2165-7939.1000205

These journal papers have been subjected to blind peer review practice by international editorial boards.

R3. **Magee, J, Quigley, T, McGroarty, P, Craven, P & Valletly, K (2017)** *Believably immersive VR experiences within the mining industry*, Digital or Visual Products. (Digital Media) (**Multi-component output:** 1 Digital Product, 1 Research Report, 1 Confidential report, 1 Conference Exhibition), **2 Awards (A1, A2)**

R4. Harpur, A., Haslam, N., McGrath, S., Fu Wu, S., Morales Cantana, E., Cooke, T., Donnelly, L., **Magee, J. & Wilson, S. (2018)** *Axial3D Insight*, Axial3D, Belfast June 18 (**Multi-component output:** 3 software applications, 1 confidential report, 1 conference abstract, 1 conference exhibition, 1 invited talk), 12 high profile commercial events (Japan, Germany, USA, UK) improving medical sector visibility. **1 Award (A3)**

- R5. **Maguire, G. (2019) HUMAIN**, Software, Belfast. **(Multi-component output:** 2 databases, 2 journals, 1 confidential report, 1 website, 1 movie trailer, 4 conferences/talks)

Awards

- A1. 2017: Innovate UK certificate of excellence for KTP009750 (graded 'outstanding')
 A2. 2018: THELMA finalist for Knowledge Exchange initiative of the year
 A3. 2020: Innovate UK certificate of excellence for KTP010763 (graded 'outstanding')

Selected Research & Collaborative Industry research funding

- G1. Magee (PI), EP/E500676/1 Academic Fellowship Programme x 2 "The Digital Human Project" RCUK (2006-2012), **GBP250,000**.
 G2. Magee (PI), Quigley (Co-I), KTP009750: "To develop a virtual 3D marketing system that is distance editable, for simulation of modular quarry equipment installations tailored to the customer's geographic environment." Innovate UK, Invest NI and CDE Global (2014-2016) **GBP89,333**.
 G3. Magee (Co-I), KTP010763: "Development of a 3D web-based visualisation system, for use by medical professionals, enabling realistic and accurate representation of anatomy at a pre-production stage" Innovate UK, Invest NI, AHRC and Axial 3D (2017-2019) **GBP147,840**.

4. Details of the impact

Impact on commerce and the economy:

I1: The economy by directly securing GBP7,733,777 industry collaborative R&D investment, and influence on unlocking Government funding of GBP4,900,000 for the engineering sector and approximately GBP7,000,000 for the Animation sector, and venture capital funding of USD3,000,000 for medical printing, shaping the sectors.

We **embedded** creative industries capability into manufacturing and medical printing sectors, contributing to the Invest NI's 2020 global marketing strategy. Better access to finance was unlocked, through funded programmes from embedding digital realism, design-led research (**R1, R2**) and immersion into new sectors resulting in two completed KTPs (**£237,233**). The CDE case study (**R3**) was the second of three follow-on KTPs evidenced by Invest NI to **unlock additional resources for new funding allocation for NI (C5: GBP4,900,000 for 2018-2023)**. It directly informed innovation with Quigley securing a FUSION programme with KES Ltd. (**GBP39,000**) while Magee & Quigley secured ConnectED funding to Digitise the Heavy Engineering sector work with 9 other companies (**GBP39,959**). Maguire's research was explored and developed (2010-2016) leading to a **spin out company HUMAIN**, attracting **start-up investment of GBP668,680**, in addition to Innovation Ulster Ltd. (**GBP100,000**), TechStart NI and Crescent Capital (**C9**). They secured **GBP593,524 Development funding** from 5 awards by Invest NI, NI Screen (2017-2019) and **GBP450,000 Research funding** from UKRI Audience of the Future (2019/2020) innovating with automated facial rigging (**C9**). They were listed as CogX, Createch Ones to Watch 2020. **"The public dissemination and profiling significantly improved the visibility of the company within the medical sector"** (**C2**), benefiting Axial3D who secured **USD3,000,000** (07-2019) to scale their technology to the United States market (Jul 2019) reaching the Global Digital Health 100 list 2020 (**C2**). Magee is a Co-I and HUMAIN an industrial partner on **1 of 9 national Creative Industry Clusters** (Future Screens NI) funded by AHRC (AH/S002855/1) securing **GBP5,705,381** industry-collaborative funding and attracting approximately **GBP7,000,000** matched contributions including, for example, NI Screen (**GBP4,800,000**).

I2: Direct sales growth in Animation (GBP1,153,777) and Medical Printing (GBP251,000) and contribution to Engineering (GBP23,237,000).

CDE **increased sales from GBP23,107,000 to GBP46,344,000** (2015-2017) as they shortened time to market through 'digital' client acceptance (**C6, p9**). Global tenders scaled up two-fold securing **GBP10,000,000** contracts digitally showcasing more complex machines (**R3**). With the support of Invest NI, Magee led (Co-I Quigley) a regional strategy, **unlocking a further GBP39,959 to digitally transform the heavy engineering sector**, currently enabling 9 SMEs to

develop digital content through a COVID-19 Recovery Project. Axial3D acknowledged a sales **increase of 1000%** over the period of the KTP (2017-2019), with the final month of the programme **securing more sales than the previous two years combined (GBP251,000) (C2)**. A design ethos was **embedded** within the company. Axial3DInsight (2018) has been enhanced and new software (a3dthree and a3dperspective, 2019) enabling the company to become an Amazon AWS partner, opening new sales channels (**R3, C2**). ***“The introduction of design thinking-based approaches to product development has radically altered not only our strategy but also how we formulate and execute on our strategy” (C7: Axial3D, CTO)***. HUMAIN secured **GBP1,153,777 across 48 contracts (C9) with 16 international partners** (inc. Microsoft, Google, Activision, Warner & HBO) and GBP100,000 of AWS credits through the Nvidia Inception Program. It is 1 of 10 high growth businesses selected for Catalyst Inc. elite business scaling programme.

13: Employment generation of 49 high skilled creativity-led jobs

49 high skilled jobs (headcount: 49; FTEs: 39) **were created within industry, directly resulting from the research**. Within CDE, a Digital Content Department was established creating **5 jobs in 3D modelling and graphic design (C6)**. Quigley's FUSION programme employed 1 Associate, embedding 3D immersive design within a HVAC company. Axial3D **increased employment from 6 to 24** (headcount: 18; FTEs: 18) including 5 machine learning programmers as a direct result of the design-led changes driving software development (**C7**). Since August 2017, HUMAIN has **recruited 25 staff** (headcount: 25; FTEs: 15) ranging from modellers and animators to programmers and machine learning experts. These include 11 directly employed, 9 through NI Screen training schemes, 3 contractors, 1 KTP Associate (KTP10860) and 1 Doctoral Training EngD with Bournemouth University, deepening the relationship between both Universities. The KTP associate and 3 trainees are now in full time employment (**C9**). The Matrix Creative Technology Report 2018 recognised Maguire's research referring to him as a ***“key influence in the growth of this subsector [Animation]” (C3)*** while NI Screen describe him as ***“extremely significant” among partners, with an “extensive” contribution where he “played an enormous part in taking the screen industry to its present level in Northern Ireland” (C10)***.

Impacts on the health and wellbeing of people:

14: Transformation of pre-operative patient care through surgical effectiveness and patient communication (approximately 60 case studies)

Axial3D's internationally adopted software, **with approximately 60 anonymised published case studies**, enables surgeons to make precise pre-surgical decisions **within 48hrs of order**, dramatically accelerating procedures and aiding patient consent (**C2**). Since 2017, it has transformed the operative workflow, ***“reducing unwanted variation in interpretation, between doctors”*** when viewing medical imaging scans through interactive 3D models and 3D prints and affords ***“contingency”*** for pre-operative planning (**C1**). It ***“resulted in a more streamlined service and better user experience”*** through the design-led approaches (**C8**). An **average of 62 minutes is saved per surgical procedure** and over 3.5 hours for complex cases. **50% of surgeons changed their pre-operative plans with a further 47% performing these plans faster. 98% of patients reported “great improvement” in patient communication** using the technology (**C2**) and a Surgeon states that this is ***“cutting edge” technology***. He goes on to say ***“what these images and these models now do is really empower the patient by giving them autonomy over their decision making and I think that is a huge advantage” (C1)***. Recovery times were reduced by 16% and in 15% of cases the surgical outcome would have been unachievable without the technology (**C2**).

Impact on practitioners and delivery of professional services:

15: Practitioners and professional services developing national case studies, establishing excellence in the region and mentoring/supporting the sector.

The CDE Global and Axial3D KTPs directly impacted on Northern Ireland's positioning as a **regional leader in excellence performance across the UK**. Ulster University is in the top 5% of UK KTP providers in terms of delivery, with **38% of its KTPs graded outstanding** compared to 24% nationally (**C4**). These KTPs assessed as outstanding have helped secure significant

government financial support for the programme (C4, C5). CDE's products were digitally experienced at 9 major international expos and many inward visits, with combined attendance of approximately 100,000 people. This **"allowed us to differentiate ourselves in a very competitive global market and helped us to exceed our revenue targets for 2016"** (C6). HUMAIN's *"amazing technology"* (Abovitz, R, Magic Leap, personal communication 29/11/2020), drives sectoral change within face reconstruction to deliver faithful interpretations of photorealistic and non-photorealistic character performances (R5). It has been used in Activision's video game Call of Duty: Black Ops Cold War and trailers for Magic: The Gathering, and Microsoft Halo and in the development of Microsoft's HoloLens. 6 people received design training in CDE (C6) and 4 within Axial3D (C7) during the KTP programmes. Innovate UK highlighted the benefits to the Axial3D associate; enabling them to engage internationally with award winning credentials in this cutting-edge sector (C4). Axial3D's case study presented at SXSW2019 cited **the world first renal operation using 3D printing, with the consultant hailing the technology as "invaluable" in pre-operative planning** (C2). So much so, in one seemingly terminal case of paediatric heart surgery, surgeons **"couldn't find a way of operating on this young baby"** and were preparing to inform the parents. Axial3D's technology enabled a **"level of insight that otherwise wasn't available"** (C1), successfully conducting the operation. A spinal surgeon stated that this technology was now **"an essential part of pre-operative planning in complex spinal cases"** (C2), while The UK Government Health Secretary (2020) announced how this technology was **"helping to transform surgery"** (C2).

Maguire is on NI Screen's Board of Directors (2015 - 2023), responsible for annual investments of **GBP11,890,000**, through the Northern Ireland Investment Committee. He leads the skills working group setting the regions training policy and employment of approximately 90 trainees and **"he is key amongst the influences that have ensured over GBP5,000,000 has been invested in games development and production over the past 3 years"** (C10). NI Screen cites the success of HUMAIN shaping such decisions being **"an important exemplar within the screen industry and [having] created a path to follow"** (C10). Maguire's research (R5) has contributed to the shaping of a **GBP61,000,000 Screen Media Innovation Lab (SMIL)** proposal as part of the Belfast Region City Deal (C10). This Virtual Production centre will address industry needs of specialism in relation to Film, Animation, Immersive (AR/VR/ MR) and Games **"The potential significance of SMIL is hard to gauge but will be in the tens of millions annually"** (C10).

5. Sources to corroborate the impact.

- C1. Irish Tech News (5 Jan 2021), *How Axial3D and AWS cleared the Northern Irish kidney transplant backlog during the current pandemic*, The Irish Tech News Podcast.
- C2. Testimonial from CSO & Founder of Axial3D Ltd. evidencing a range of impacts including quantifiable data and extracts from >60 published case studies.
- C3. Matrix Creative Technology Report 2018, p17.
- C4. Testimonial from Innovate UK, KTP Manager
- C5. Testimonial from Invest NI Director of Innovation, Research & Development, outlining the economic benefits of high performing KTPs (Axial3D and CDE Global) unlocking government money for these programmes regionally.
- C6. CDE KTP009750 End of project report (2017) which includes the company report sections on impact supplied to Innovate UK, assessed as outstanding.
- C7. Axial3D KTP010763 End of project report (2019) which includes the company report sections on impact supplied to Innovate UK, assessed as outstanding.
- C8. 3DHEALS Influencer Interview : with CTO of Axial 3D [25th Jan 2018]
- C9. HUMAIN Accounts statement verifying contracts with leading organisations (Microsoft, Google, Activision, Warner & HBO and others), HUMAIN R&D grant awards and evidencing employment records.
- C10. Testimonial from CEO NI Screen, outlining the influence of Maguire and HUMAIN on the NI Screen sector growth to date and its future trajectory.