Institution: University of Hull

Unit of Assessment: 11 Computer Science and Informatics

Title of case study: Virtual Environment Training Applications

Period when the underpinning research was undertaken: 2001 to present

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:
Warren Viant	Senior Lecturer	2001 – present
Yiannis Papadopoulos	Professor in Computer Science	2001 – present
Roger Phillips	Research Professor	1990 – 2011
Andy Beavis	Honorary Professor	2008 – 2011
James Ward	Research Lecturer	2001 – 2019
Neil Gordon	Senior Lecturer	2001 – present
Qingde Li	Lecturer	2001 – present
Xinhui Ma	Lecturer	2013 – present
John Dixon	Lecturer	2016 – present

Period when the claimed impact occurred: 2014 – 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Research into Virtual Environments and Training Applications (VETA) created state-of-the-art commercial tools for **radiotherapy** and **emergency service training**. VERT is a system for advanced radiotherapy training commercially offered by Vertual Ltd, a University spinout. Vertual occupies a global monopoly with 35 systems in UK hospitals and 154 systems worldwide, providing cost-effective superior training on safe treatment methods and equipment calibration. LIMA (Large Incident Multiple Agency) and VIC (Virtual Incident Command) are virtual environments that allow training through distributed simulation of major regional incidents. Lampada Ltd is a University-owned company currently offering LIMA, VIC**,** and related products to a third of UK Fire Services. These systems allow realistic training and preparation for rare incidents off-line, and without disruption to service provision. The impact of VETA is economic, via revenues and jobs, and social, via improvement of public services.

2. Underpinning research

Since 2001, the University of Hull (UoH) nurtured a vibrant research environment in the area of virtual and augmented reality, which has yielded a stream of innovative research applications with impact. The VETA case study reports on upscaling of research and impact first reported in the Vertual impact case study of REF2014 and its expansion to other application areas. UoH's research environment includes the Virtual and Augmented Reality and Simulation (VARS) research group, and the Hull Immersive Visualisation centre (HIVE). Applied research in these two centres underpinned commercial applications that employ virtual environments and simulation for training professionals. Two areas were targeted: medical radiotherapy training (section 2.1) and emergency service personnel training for disaster management (section 2.2).

2.1. Virtual training for radiation therapy and calibration

The research underpinning the Virtual Environment for Radiotherapy Training (VERT) started in 2006 in a collaboration between HIVE and the Medical Physics Department at the Health Education Yorkshire and Humber NHS Trust. The researchers involved were Roger Phillips, Andy Beavis and James Ward, the latter two are currently the CSO and CTO of Vertual Ltd - the spin out commercialising the application [e2]. The objective of this research was to investigate innovative and beneficial applications of immersive environment technologies in radiotherapy treatment of cancer, in terms of dose, beams, anatomy, equipment and potential variations from planning to review of radiotherapy treatments. First results were published in 2007 [1] describing the development and evaluation of a basic training system for radiotherapy treatment machines. This was followed by significant awards of research grants and the publication of results on dosimetry enabling more advanced features [2]. The concept has since been enriched and VERT

today provides detailed, realistic simulations of linear accelerator (LINAC) treatment machines from major manufacturers Varian, Elekta and Siemens. A LINAC is the device commonly used for external beam radiation treatments for patients with cancer. It delivers high-energy x-rays or electrons to the region of a tumour. Treatments are designed in such a way that they destroy the cancer cells while sparing the surrounding normal tissue. Treatments using these machines must be done carefully for safety and effectiveness, and equipment must be calibrated accordingly. Typically, a radiation oncologist prescribes volume and dosage while a medical physicist and a dosimetrist determine how to deliver the dose and calculate the amount of time it will take the accelerator to deliver that dose. A radiation therapist then operates the LINAC and gives patients their daily treatments. In VERT, these processes are simulated in fine detail; for instance, authentic hand controls have been interfaced to control the LINAC, enabling trainees to develop psychomotor skills. Simulation extends to calibration and quality assurance processes.

From 2014 onwards, research focused on life-sized virtual simulation of the treatment room with all its equipment, controls, a simulated patient and different radiation types. The branching out into different radiation therapies is significant, because such in situ training requires vastly different facilities, an issue not encountered for virtual training. This process of research-led functionality continues, with the latest research on high precision implicit modelling from the Hull team [3] further strengthening the VR training software's volumetric rendering capability. In a recent grant by the Welcome Grant [4], Xinhui Ma has advanced image analysis on CT and MRI datasets, a corner stone of VERT, as well as stereo photogrammetry images for the identification of homologous landmarks in soft tissue. The visualisation functionality within VERT also continues to advance drawing upon Qingde Li's work on advanced segmentation and modelling. VERT provides visualizations that go beyond what the trainee would see in the actual treatment room. For example, the patient can be rendered transparent to reveal the location of suitably segmented tumour and neighbouring organs. Similarly, the normally invisible radiation beam can be made visible, to better understand its spatial relationship to other structures for planning and dose assessment. Overall, this type of virtual radiotherapy training which is continuously advancing through this research optimises the effectiveness of treatment whilst minimising the risk to patients and to very expensive equipment.

2.2. Virtual emergency service training and disaster management

Since 2014, VARS, HIVE and the Dependable Intelligent Systems (DEIS) research groups worked together with Humberside Fire and Rescue Service (FRS) to create the management of Large Incident Multiple Agency (LIMA) and Virtual Incident Command (VIC) - two applications for training professionals in emergency services. VARS offered research expertise on Virtual Environments and gamification, while DEIS expertise on dependability of systems including that of communication protocols. LIMA is a now a software system that supports UK guidelines for *Control of Major Accident Hazards* regulatory multi agency training events through the simulation of regional incidents with application to the fire service. VIC is a virtual environment for the training and assessment of incident commanders in some of the most risk critical parts of the emergency services. The underpinning research of these two systems is partly founded on VERT technology for virtualisation, but also includes research on gamification specifically on creating useful interactive simulations of major disaster events that by their nature are too infrequent and complex to effectively train for [5].

LIMA and VIC are distributed and communicate through networks providing multi-nodal solutions for distributed training where firefighters are able to risk-assess premises and disseminate the information to the command centre and vice versa, which in turn enables realistic and effective training. To this end, VIC and LIMA connect to other safety critical products within the Intelligent Response suite offered by Lampada; they include Command and Control (C&C), Web Risk Management (WRM), and Technical Fire Safety (TFS). These products can be used in the context of virtual training but also for real management of actual emergencies. They offer functionality for real-time data collection and dissemination of risk assessments from multiple sites to support the critical tasks of tracking, mobilising and controlling all fire safety appliances and assets from headquarters during emergency operations. WRM, for example, communicates real-time information about the risk faced by firefighters as they visit the site of an incident, for example any flammable exterior cladding on a building, like that in the Grenfell Tower disaster [e1, e10]. LIMA,

VIC and Intelligent Response use a robust, resilient, domain specific communications protocol, an early version of which was developed and verified via HiP-HOPS, simulation and model-checking in the University of Hull [6]. The research that led to this continuous stream of impactful state-of-the-art commercial systems integrates components that span from Virtual Environments through Digital Learning to Dependable Computing. We list six indicative papers and grants.

3. References to the research

[1]. Bridge P, Appleyard RM, Ward JW, Phillips R, Beavis AW (2007) The Development and Evaluation of a Virtual Radiotherapy Treatment Machine using an Immersive Visualization Environment, *Computers & Education*, 49 (2), pp 481-494, Elsevier

[2]. Beavis A, Ward J (2012) The Development of a Virtual Reality Dosimetry Training Platform for Physics Training, *Medical Physics*, 39(6):3969, AAMP & Wiley Online

[3]. Qi Q, Li Q, Cheng Y, Hong Q. (2020) Skeleton Marching-based Parallel Vascular Geometry Reconstruction Using Implicit Functions., *Journal of Automation and Computing*, 17:30–43.

[4]. Ma X. (PI) et al, (2017-2019) Three-dimensional analysis of maxillofacial growth in patients with cleft lip and palate, *Wellcome Trust Grant* #205923/Z/17/Z.

[5]. Viant W, Purdy J, Wood J, (2016) Serious games for Fire and Rescue training, *8th IEEE Computer Science and Electronic Engineering Conference (CEEC)*, Colchester, UK, DOI: 10.1109/CEEC.2016.7835902 .

[6]. Dixon JWD, & Grey DJ (2015) Introducing the Emergency Propagated Reference Network (EPRN): A practical and efficient ad hoc network for emergency response. *8th Int'l Conf. on Computer Games, Multimedia and Allied Technology*, Singapore, DOI: 10.5176/2251-1679_CGAT15.12 (+ fine details in Dixon's PhD thesis)

4. Details of the impact

The impacts primary occurred though the commercialisation of two university spinouts: Vertual Ltd [e2], and Lampada Digital Solutions [e3]. Significant impacts were achieved in two areas: **medical services** via improved radiotherapy training (section 4.1) **emergency services** via improved training and management of major disasters (section 4.2). The impacts are economic through creation of revenues and jobs, and social, through improvement of critical medical and emergency services. Virtual training incorporates digital learning; thus in section 4.3, we discuss developments in connecting VR with digital learning at Hull.

4.1. Impact on medical services via radiotherapy training

Vertual has effectively **a global monopoly** on VR radiation training, as the only provider of this type of VR training. The beneficial impact is evidenced by the adoption of VERT's multi-award-winning system throughout the UK. There are currently **VERT systems** at **12 Universities** and over **35 radiotherapy teaching hospitals** in the **UK;** effectively covering all radiotherapy trainees in England. There are **154 VERT systems** installed across **33 countries** covering all continents. In comparison, in REF2014, we reported 92 installation in 16 countries. For an interactive map of installations and a list of users see [e6]. The company employs a network of **28 distributors** globally [e1]. The expansion is clear and success is due to VERT offering a safe and effective training environment that reduces training costs, increases capacity, provides more effective training and ultimately improves patient safety (see **client testimonials** in [e1]).

The above is translated to economic success. Since the last REF, the gross profit of Vertual grew to **£1.64M with £2.88M annual turnover in 2019** [e1]. In comparison, in REF2014, we reported a total 3-year gross profit of £965k and £2M turnover. The company employs **20 people with an average salary of £36k** including eight full-time software developers and four radiotherapy product specialists. In comparison, in REF2014, we reported 10 staff with an average salary of £30k. This is significant, as the company is based in the Humber region where traditional industrial employment is declining, creating a backdrop of higher unemployment and lower salaries. Furthermore, the economic knock-on effects observed on an emerging supply chain are considerable. For example, within the UK, **Vertual Ltd partners** that supply hardware and services for VR systems reported over **£825k annual hardware sales in** the year ending **2019**, including installation and support services [e1]. In comparison, in REF2014 we reported annual benefits of £400K.

Vertual has grown substantially as the scope of VERT has grown with research that has led to more advanced features, and as radiotherapy professionals have identified innovative applications beyond its initial scope. Vertual has now expanded its activities to graduate and postgraduate RT training, continuing professional development, anatomy training, skills assessment, patient awareness, nurse training, staff training and research. Several nationally funded training programmes, including the UK, Australian and New Zealand health authorities all have adopted VERT systems for training purposes. The first six Australian installations were funded by the Department of Health and Ageing in Australia [e4]. The New Zealand government provided $1m in funding for VERT [e5].

Vertual nurtures a community of professionals in the area of VR training. It provides financial support for research and educational projects, regularly sponsors student graduation awards and prizes in the UK, US and Canada, and funds attendance at conferences [e1]. Finally, there is now a vibrant **VERT user community** [e7], which continues to actively conduct and publish research and studies evaluating VERT, expanding its scope and application, and sharing best practice. The beneficiaries are users of VERT and professional in the area, evidenced by the strongly attended VERT User Meetings including a meeting for German speaking users held in Austria Wien University (December 2019), the VERT Int'l User Meeting 2019 held at Inholland University in Delft (March 2019) and VERT UK Users' Research Meeting (November 2018-20). An annual user meeting is held in the USA, to cater for the increasing number of US users (39 VERT installations in the USA and Canada and growing).

4.2. Impact on emergency services

Traditional training on responses of emergency services to incidents is essential but costly, especially for the larger scale events, which involve a great number of actors, and can cause a significant disruption to service provision. Our collaboration with Humberside FRS in this area goes back to 2004 when in the context of SEED, a European Development Fund project, we first started to investigate the problem. VIC and LIMA software applications were developed in the period with input from Humberside and North Staffordshire FRS precisely to address these requirements and training needs. A related suite of products called Intelligent Response with connectivity to LIMA and VIC also resulted from collaboration with Humberside FRS. Intelligent response includes applications C&C, WRM and TFS that can used beyond training for management of actual emergencies [e10].

The input of the two FRS in the design of VIC and LIMA made the environments realistic and applicable for training purposes. The Operations director at HFR Solutions states: "*LIMA offers Incident Management Teams a professional platform to replicate realistic site incidents with clear visual perspective on the ensuing incident, actions required and the impact of these actions on the incident, both on and off-site.* ***This training and incident management software transforms how we test the tactical & strategic management teams****, to effectively resolve emergency incidents. It has* ***enhanced the learning experience of our delegates and provides positive engagement at all levels*** *with fantastic feedback throughout our training courses*." [e9]

Lampada, a University-owned company, is commercialising LIMA, VIC and intelligent Response. Lampada is fast growing and now supplies software and services to a third of UK's FRS [e3]. Clients of Lampada include Humberside, Cleveland, Norfolk, Shropshire, Staffordshire, Warwickshire, East Midlands, Hertfordshire, Hereford and Worcester FRS, and the list grows. Clients also include commercial suppliers of services to FRSs including Telent Ltd, a specialist company leading mission critical communications technology, and HFR Solutions, a company transferring FRS experience to the private sector. This client base has grown fast because users experience and report improved training at lower costs, improved operational capacity and ultimately improved quality of emergency service provision. Lampada's income is generated both from the sale of licences and specific project work related to applications [e8]. Since its inception in 2017, the **revenues of Lampada increased from £511,000 (2018) to £1,080,000 (2019) and £1,528,000 (2020).** Lampada employs **28 staff** mostly in high-tech jobs boosting local employment. Beyond direct income and job creation, Lampada also annually trains several Computer Science students, via internships and placements in courses that include a year in the industry. The latter contributes to the employability of students and the improvement of the regional and UK workforce [e3].

4.3. Related work on Digital Learning & Virtual Environments – future outlook

We are very proud to have created, sustained and continually developed over decades a body of applied research and systems that improves our **public** medical and emergency **services** in the times of a **pandemic**. In relation to impact on public service, it is worth mentioning the relevant work by Neil Gordon on approaches to e-learning which was influential in shaping the successful Chinese government response to the virus in their education system [e12]. The keystone to this work was a 2014 Research Report for the Higher Education Academy on Technology Enhanced Learning and Flexible Pedagogies [e11]. The NHS is currently using this work in their guidance on implementing technology-based training. Given the impact of this work, department is currently exploring synergies with VETA environments as the next step to support enhanced learning.

Still in the area of virtual environments, the DEIS and VARS research groups are collaborating on research on digital art and intersections with philosophy and science. Applications of this work are increasingly becoming impactful. A result of this work is TIMAEUS [e13] a digital art studio environment that enables creation of personalised 3-dimensional virtual sculptures. These sculptures can be customised with pictures, videos and music, which are embedded and can be experienced in different ways with the capability of zooming in and out, rotating, and viewing from different angles. TIMAEUS is used in applications from art therapy to education on philosophy and literature; examples are the creation of a Virtual Digital Stoa and an Alternative Virtual Odyssey. Papadopoulos gave an invited talk on "Meeting Epictetus and Seneca in a Virtual Stoa: Classical Wisdom as Emotional Education of the Future" in the Roman Forum during the annual Literature Festival of Rome' (2019). These efforts give encouraging signs that the UoH's work into VR, training and digital learning will continue to generate exciting and impactful results.

5. Sources to corroborate the impact

[e1]. Testimonial by CTO of Vertual Ltd & including testimonials of clients [*uploaded PDF*]

[e2]. Vertual Ltd (company) and VERT (product) websites [*archived web link1, link2*]

[e3]. Lampada Ltd (company) and LIMA, VIC, Intelligent Response (products) websites [*archived web link1, link2, link3, link4*]

[e4]. Article on Australian funding for VERT [*archived web link*]

[e5]. Article on New Zealand funding for VERT [*archived web link*]

[e6]. VERT installations map [*archived web link*] & list of clients [*uploaded PDF*]

[e7]. Vertual International User Meeting 2019 [*archived web link*]

[e8]. Testimonial by CEO of Lampada - impact on emergency services [*uploaded PDF*]

[e9]. LIMA case study & statement by Operations Director of HFRS [*archived web link*]

[e10]. WRM case study & Statement by Staffordshire FRS [*archived web link*]

[e11]. Technology Enhanced Learning and Flexible Pedagogies, HEA report by Neil Gordon, 2014 [*archived web link*]

[e12]. Handbook on Facilitating Flexible Learning During Educational Disruption: The Chinese Experience in COVID-19 Outbreak, Unesco, 2020 [*archived web link*]

[e13]. TIMAEUS, Virtual Digital Stoa, Alternative Virtual Odyssey, paper on invited talk on "Meeting Epictetus and Seneca in a Virtual Stoa" in the annual Literature Festival of Rome' [*archived web link1, link2, link3, link4*]