Institution: University of the West of Scotland

Unit of Assessment: 12: Engineering

Title of case study: Technological and economic impact from inter/multidisciplinary collaborative product and process development.

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:
Dr Parag Vichare	Lecturer	2011 - 2020
Prof Desmond Gibson	Professor	2014 - 2020
Prof Stuart Reid	Professor	2012 - 2017
Prof Abdul-Ghani Olabi	Professor	2013 - 2018
Dr Adelaide Marzano	Senior Lecturer	2014 - 2020
Mr Anthony Leslie	Senior Lecturer	2014 - 2020
Dr Luc Rolland	Lecturer	2017 - 2020

Period when the claimed impact occurred: 2017 - 2020

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

1. Summary of the impact

Technological and economic impact was achieved through innovative inter/multidisciplinary collaborative product and process development and is presented in this impact case study as a portfolio of three individual projects. The impact of these is evidenced through corresponding technology adoption by industrial collaborators in the fields of medical science, optics and sustainable urban infrastructure. The developed products and processes are operational and have resulted in innovative medical procedures at Histocell (Spain); sector-leading optical coating infrastructure at Helia Photonics Ltd (HPL- Scotland) and JAVAC (China); and remanufacturing processes at WEEE Scotland Ltd (WSL), for mass-refurbishment of street-light-housings for Glasgow City Council (GCC).

2. Underpinning research

Context

With a strategic vision to focus on pioneering commercially exploitable product innovations across a spectrum of application areas **[3.A-3.D]**, the team conducted research in product design and data management **[3.1,3.2],** process/work-cell design and work-study analysis using digital mock-up tools **[3.2,3.3]** and environmental impact analysis **[3.4, 3.5].**

Key findings:

Nanokicking (Project I): UWS research in product design (**Vichare, Cameron**) has led to the invention of cultureware capable of harvesting induced nano-vibrations through a bio-reactor for clinical trials. The research supported the team (names of key individuals from 3.1 below), working collaboratively with the team at the **University of Glasgow** (**Dalby**), achieving an entirely new discovery within tissue engineering which involves harnessing nano-vibrations for growing surgical bone graft. Prior to this work, it was reported that 1KHz nano-vibrations can stimulate osteogenesis in 2D and 3D cell culture **[3.1].** However, rotary/perfusion mechanical bioreactors used in the previous investigative projects were incommodious, as it was difficult to detach individual clinical samples from the cultureware, for clinical procedures. Underpinning product design research **[3.1]** (injection mould design, mould manufacturability, and mould flow analysis) has shown that the bio-reactor system fitted with an innovative six-well cultureware with toroidal shaped magnets incorporated in the base of each well can be realised and utilised for rapid osteogenesis. The cultureware was produced using an insert type multi-ejection stroke injection moulding technique. The cultureware and thus collagen and mesenchymal stem cells (MSCs), all resonated at 1KHz with an amplitude of 30nm, and have produced clinical grade osteogenic-cells.

Rapid coating processes (Project II): Underpinning research (**Vichare**) on dimensional variation analysis **[3.2]** and UWS' original in-house collaborative product/process development was applied for designing and manufacturing critical opto-mechanical components of the Microwave Plasma Assisted Sputter (MPAS) system. This was in support of the research at the UWS's Institute of

Thin Films, Sensors and Imaging (ITFSI) to develop and patent a unique retrofittable plasma source for assisted deposition **[3.6]**. This is a high throughput MPAS system for rapid coating processes. Prior to this research, the technological barrier for optical coatings was the limited capacity of commercial Electron Beam Deposition (EBD) systems. Therefore, the demand for a high throughput versatile system for optical coatings was evident. This included complex rotating drum sub-assembly with critical tolerances between optical and mechanical components of the system. The resulting MPAS system was designed to support four sputter targets. Industrial trials have shown a fourfold increase in the coating surface area and a sixfold increase in throughput, which has resulted in a sector-leading operative optical coating system.

Remanufacturing of street-light housing (Project III): The research team **(Vichare, Olabi, Marzano)** investigated and developed a large-scale remanufacturing process for replacing sodium lamps in existing street-light housings with LED lights. Underpinning research **[3.5]** included investigation of a chemical-stripping process for aluminium alloy housings with polyester-based powder coatings. The ground-breaking research including life-cycle assessment **[3.4]** has quantified significant chemical waste and associated environmental impact with de-coating process. A re-coating process was developed, which was applied on cleaned light housings without removing their original coating. Re-coating trials were conducted on both i) de-coated castings and ii) cleaned/wiped castings (with existing coating) for comparison purposes. Following this research, it was concluded that the de-coating process is not required; thereby reducing chemical waste and the associated negative environmental impact.

WSL have stated that **[5.6]:** *"Re-coating process for existing aluminium light-housings was definitely a turning point for mass refurbishment projects, where we realised that chemical stripping process can be avoided. The similar approach can be applied to other refurbishment cases as well."*

Research undertaken in work-study and ergonomic analysis has resulted in a design and fabrication dedicated remanufacturing work-station, which reduced disassembly process time by 68% **[3.3].**

The overall enhanced product development capability at UWS in delivering innovative products and processes, has gained significant industry recognition and resulted in a number of further Innovate UK funded Knowledge Transfer Partnership (KTP) projects **(Vichare, Leslie, Gibson, Rolland)** (Helia Photonics Ltd, Shanghai-JAVAC (China), Consult Lift Services, Teer Coatings, Alphasense, GasClip (USA), Phoenix Instinct Limited, Sanondaf UK, ACS Clothing Limited) **[3.E-3.L]**.

3. References to the research

3.1 Campsie, P., Childs, P. G., Robertson, S. N., Cameron, K., Hough, J., Salmeron-Sanchez, M., Tsimbouri, P. M., **Vichare, P.,** Dalby, M. J. and **Reid, S.,** (2019) Design, construction and characterisation of a novel nanovibrational bioreactor and cultureware for osteogenesis. *Scientific Reports*, 9: 12944. https://doi.org/10.1038/s41598-019-49422-4

3.2 Vichare, P., Martin, O. and Jamshidi, J., (2014) Dimensional management for aerospace assemblies: framework implementation with case-based scenarios for simulation and measurement of in-process assembly variations. *The International Journal of Advanced Manufacturing Technology,* 70(1-4): 215-225. https://doi.org/10.1007/s00170-013-5262-9

3.3 Marzano, A., Vichare, P. and Munoz de Escalona, P., (2018) Design and Ergonomic Analysis of the Waste Electrical and Electronic Equipment (WEEE) Remanufacturing Workcell Fixture Using Digital Mock-up Environment, *CIRP-Proceedia*, 78: 353-358. https://doi.org/10.1016/j.procir.2018.10.002

3.4 Cheung, W., Leong, J.T. and **Vichare, P.,** (2017) Incorporating lean thinking and life cycle assessment to reduce environmental impacts of plastic injection moulded products. *Journal of Cleaner Production*, 167: 759-775. https://doi.org/10.1016/j.jclepro.2017.08.208

3.5 Chinombo, M., **Vichare, P.,** and Cheung, W. M., (2018) Comparison of environmental life cycle analysis of aluminium alloy (LM 6) street light housing and aluminium alloy (Al Si12Cu1{Fe}) housing, *11th International Conference on Sustainable Energy and Environmental Protection (SEEP 2018),* 8th to 11th May 2018, Paisley, UK. Output can be supplied by HEI on request.

3.6 Child, D., **Gibson, D.,** Placido, F. and Waddell, E., (2015) Enhanced hollow cathode plasma source for assisted low pressure electron beam deposition processes. *Surface & Coatings Technology*, 267: 105–110. https://doi.org/10.1016/j.surfcoat.2014.12.030

Grants

3.A Reid, S., Cameron, K., **Vichare, P.,** *Developing the NanoKick bioreactor to enable tissue engineered bone graft and use of metabolomics to identify bone specific drug candidates,* EPSRC, 2016, GBP290,447

3.B Vichare, P., Olabi, A.G., *Remanufacture strategy for street lamp aluminium castings*, Scottish Institute for Remanufacturing (SIR), March 2016 to September 2016, GBP20,485.

3.C Vichare, P., *Design of dedicated re-manufacturing workstation and handling equipment*, Scottish Institute for Remanufacturing (SIR), August 2017 to June 2018, GBP40,180

3.D Gibson, D., Song, S., Vichare, P., *Novel microwave plasma sputter (NMPLAS) deposition process providing high throughput optical coating*. Innovate UK; Shanghai-UK industrial challenge programme, March 2018 to May 2021, GBP387,029.

3.E Rolland, L., **Vichare, P., Gibson, D.,** *To embed advanced robotics and automation design knowledge in order to exploit emerging market opportunities and increase productivity*, Innovate UK: KTP with Helia Photonics Ltd, August 2019 to July 2021, GBP122,719

3.F Vichare, P., Obeid, O., Olszewska, J., Rolland, L, *To embed mechanical engineering & modular design framework expertise, SMART control knowledge and product data management (PDM) to develop a new NPD capability in support of Consult Lift Services,* Innovate UK: KTP with Consult Lift Services Ltd, August 2020 to January 2023, GBP137,761.

3.G Gibson, D., Song, S., **Vichare, P.,** Birney, R, *Develop a new range of optical coating machines and optical coating services,* Innovate UK: KTP with Teer Coatings Ltd, November 2020 - July 2023, GBP169,886

3.H Gibson, D., *To embed linear variable filter (LVF) and miniaturised infrared spectrometry technology to support design and launch a new range of optical sensor systems,* Innovate UK: KTP with Alphasense, June 2019 to May 2021, GBP115,590.

3.I Gibson, D., Hutson, D., Song, S., **Vichare, P,,** *Development and productionisation of a bespoke ultralow power consumption methane sensor,* Gas Clip Technologies Inc (USA), 2021 GBP451,022.

3.J Leslie, T., Murmu, T., *Embed advanced composite structures finite element design capability to underpin the design and development of a new range of SMART Ultralight wheelchairs,* Innovate UK: KTP with Phoenix Instinct Ltd, June 2019 to May 2021, GBP122,631

3.K Leslie, T., Adel-Wahab, A., Docherty, S., Durrant, A., McKay, W, *Embed engineering and microbiology expertise to facilitate the design, development, testing and launch of the next generation of microbial disinfection and decontamination technology,* Innovate UK: KTP with Touch-less Hygiene UK Limited, April 2019 to March 2021, GBP115,174

3.L Yaseen, M., Rolland, L., Ratab, M., MacKay, W., **Vichare, P., Marzano, A.,** *Embed automation and physical chemistry expertise, underpinning the design, development and implementation of a novel in-line garment sanitisation process,* Innovate UK: KTP with ACS Clothing Ltd, August 2020 to January 2023, GBP145,848

4. Details of the impact

History of impact generation

Research in through-life product development has been pivotal in several commercial exploitations at UWS: **(1)** An early collaboration between the tissue engineering group from the University of Glasgow (**Dalby**) and ITFSI research groups (**Reid**) from UWS resulted in a programme of investigative projects during (2011 to2014) for stimulating osteogenesis in MSCs, using externally induced mechanical nano-vibrations (nanokicking). A follow-on project, aimed at developing a clinical infrastructure for surgeons to develop a bone graft, demanded a specialised cultureware to be

installed on a nano-vibrational bioreactor. Thus, expertise in product design and data management, injection mould design and dimensional variation analysis (**Vichare**) from the Engineering group at UWS was sought (2014 to2016). This led to a collaboration with ITFSI research groups to investigate the design feasibility of novel cultureware (Project I). **(2)** This successful multidisciplinary collaboration extended to further investigate mechanical design aspects of various opto-mechanical systems and sensors development projects within ITFSI (**Gibson**). This later resulted in the successful realisation of a sector-leading MPAS system (Project II). **(3)** Within its Council Strategic Plan (CSP), GCC has made a commitment to be one of the most sustainable cities in Europe over the next 20 years. GCC and local authorities are working with WSL on several recycling projects. WSL is a fully licenced Waste Management Company, committed to providing positive environmental impact not solely by offering responsible recycle and repair options, but also investing significantly for exploring re-usability pathways. The need for recycling or re-using street-light housing was first discussed with GCC in early 2016. WSL states that **[5.6]:** *"Although we have wide experience and virtuous knowledge base in processing electronic component, we wanted to extend this knowledge in recycling and re-using large castings and coating processes. Most of our recycled/re-used components have plastic housings, which can be re-used after cosmetic alteration processes. However, re-using street-light housings (made of aluminium alloy) was comparatively new area for us. Thus, we had to explore recycling and re-use options for these components with environment impact assessment."* Initial coating trials and investigation outcomes **(Vichare, Olabi)** were presented to GCC executives. This initiated a follow-on investigation on establishing a remanufacturing process for street-light housings (Project III). In response, an interdisciplinary team with expertise in work-cell design, human centric ergonomic design, life-cycle analysis **(Vichare, Marzano)** was formed to configure a remanufacturing process, focusing on designing a dedicated workstation to reduce dis-assembly time.

Technological and economic impact through products and processes adoption:
Histocell, a biopharmaceutical company based in Bilbao, **Spain**, has adopted our novel bioreactor technology and established a new production and testing process **[5.2]** of this nanovibrational system.

The CEO of Histocell, has confirmed **[5.2]:** *"Research projects aimed at adopting this technology for clinical trials, this included GBP2,800,000project funded by the **Sir Bobby Charlton Foundation landmine charity [5.2, 5.3]** and the new **Healikick consortium** which received EUR5.2m of European Horizon 2020 funding. These projects include direct funding to Histocell who are developing the GMP (Good Manufacturing Practice) grade clinical therapeutic intended for human use. We have transferred a number of nanovibrational systems to our laboratory at Histocell and have adopted the cell stimulation processes developed by your academic team to produce initial batches of osteogenic cells using this technique."*

This system consists of i) a bio-reactor with piezo actuator source attached to the vibration plate for producing nano-vibrations and ii) toroidally shaped, six-well cultureware with unidirectional ferrite magnets embedded in the base of each well for conformal attachment to the bioreactor's magnetic vibration plate. This has impacted on Histocell's capacity to introduce advanced therapeutic medical products and devices for ongoing clinical development in bone repair derived from MSCs in order to treat bone defects.

While confirming the used of these cultureware, Histocell stated that **[5.2]:** *"Through these ongoing projects, we will work with your team to test these cells in pre-clinical scenarios, to establish a GMP production process and to produce cells for first-in human clinical trial."*

HPL and the **JAVAC** facility in Shanghai, **China**, are commercially using the UWS-developed complex opto-mechanical MPAS systems. This has directly resulted from Project II and has thus provided a significant technological impact by applying underpinning research for commercial exploitation internationally.

The CEO of JAVAC stated that **[5.4]:** "*The novel MPAS process offers a disruptive technology providing up to six times enhancement of throughput compared to current state of the art Physical Vapour Deposition processes based on high temperature electron beam deposition (primary*

method used worldwide for production of optical coatings). JAVAC estimate 10 to 15 MPAS machine sales per annum with an equivalent sales value of USD7,000,000 to 10,000,000,."

This has provided JAVAC with a competitive advantage in the global optical coating market. Overall impact is contributed through mechanical system design, which involves consolidating design/manufacture requirements, applying dimensional variation analysis and managing product/process data for developing an entire MPAS and critical sub-systems.

The CEO of HPL, commented that **[5.5]**: *"This opto-mechanical system has enabled HPL to secure new business, examples include optical coating of microelectromechanical system wafers used in smart phone advanced spectrometers and large area components for holographic projectors. This has translated into additional HPL export sales of GBP180,000 per annum, set to double within the next six months (78% of HPL total sales are export)"***.**

A new remanufacturing process was adopted by **WSL [5.6]**, following revolutionary collaborative research with the company and **GCC**. A dedicated remanufacturing work-station was designed and evaluated using ergonomic principles and then fabricated and tested with a pilot batch of 100 street-light-housings; now operational at WSL. Resulting disassembly process time was reduced to an average of 9 minutes from 28 minutes; i.e. c.68% reduction in the processing time.

Considering the anticipated quantity of street-light-housings in GCC alone (~10,000), the Managing Director of WSL has confirmed **[5.6]:** *"Following the initial project pilot stage, WSL is now in prime position to secure remanufacturing contracts for subsequent phases of street-light replacement for GCC. Based on the research and results from initial remanufacturing process trials, the financial savings for GCC were estimated GBP260,000, and the turnover for WSL estimated to be approximately GBP900,000. The next two phases of the project of 15,000 units and 40,000 units are expected to generate turnover of around GBP12,500,000 over the period of the contracts with the creation of between 15 and 20 full time jobs"***.**

5. Sources to corroborate the impact

Project I
5.1 https://www.bbc.co.uk/news/uk-scotland-glasgow-west-46953192 providing an evidence of the potential impact on fighting the bone disease osteoporosis, thus use of developed 6-well cultureware.
5.2 Testimonial from Histocell, confirming technology adoption and the use of 6-well magnetic base cultureware for clinical trials.
5.3 https://www.thesbcfoundation.org/research/regenerative-bone-growth/ provides details of the project where cultureware will be used in developing synthetic bone by trauma surgeons to repair the limbs of landmine blast victims and others who have bones that have been shattered.

Project II
5.4 Testimonial from CEO of Shenghai JAVAC, confirming realisation of novel MPAS system, technological impact and resulting business growth forecast in Chinese optical coating market.
5.5 Testimonial from CEO of Helia Photonics Ltd (HPL), confirming business growth and projected areas of applications that can be attributed towards use of novel MPAS system.

Project III
5.6 Testimonial from Managing Director, Weee Scotland Limited, confirms impact of underpinning research work on coating investigation, technological impact of the remanufacturing process and the technology adoption in the company.