Industry 4.0 @ UoM

Shaping the Future of the Digital World

The University of Manchester Industry 4.0 Strategy and Vision

April 2019

NOTES:

Contents

Foreword

As the global quest for more efficiency through digitisation of manufacturing processes intensifies, and society endeavours to get to grips with the impact of automation on communities and organisations, universities are presented with the opportunity of finding innovative solutions to these challenges, and becoming powerhouses of knowledge that are integral for the supply chain of talent.

The University of Manchester is in a strong position to help lead on the fourth industrial revolution, with hundreds of researchers spanning the entire spectrum of Industry 4.0 with the overarching theme of Human-Centric Design and Manufacturing.

This report sets out a roadmap for achieving this coordinated and focussed approach. Not only does it demonstrate the wide range of our Industry 4.0 strengths, it also illustrates the highly interdisciplinary nature of our Industry 4.0 offering, aggregated under five key pillars which closely aligned to our Faculties of Humanities; Science and Engineering; Biology, Medicine and Health; as well as our Advanced Materials Research Beacon and the Manchester Urban Institute. The report forms part of the wider University of Manchester vision of becoming a world-class provider of solutions to global challenges, and the ideal partner for innovative research, training and adoption of industrial digital technologies.

Professor Stephen Yeates FRSC
Associate Vice President – Research
The University of Manchester

Preface

The fourth industrial revolution (Industry 4.0), characterised by the increasing digitisation and interconnection of product value chains and business models, is having a major impact on companies, investors and customers. Through the application of digital tools and technologies to the value chain of businesses who operationally asset intensive, industrial digitalisation enables the physical and digital worlds to be merged and can bring significant enhancements to performance and productivity.

Industry 4.0 is also opening new and challenging opportunities with its focus on new customer-centric grids. Customers will have a key role in value creation, zero-defect, low-emission production systems, and nature-inspired manufacturing that can allow us to design and operate more sustainable industrial ecosystems. It also requires a new type of employees: creative and flexible, possessing critical and problem-oriented thinking.

Manchester is the ideal place to lead this industrial revolution in the UK and internationally. A cradle of the first industrial revolution, Manchester is a good example of a city and a region that has always sought to be at the forefront of innovation and value creation. The city and region have a DNA that is characterised by innovative spirit, entrepreneurship and risk-taking. With a population of c.2.5 million and up to 200 spoken languages, Manchester is one of the most linguistically diverse cities in Western Europe. This cultural pot makes Manchester an open-minded, creative, dynamic and resilient place. The University of Manchester is a world leading research institution with a rich history and outstanding heritage. It was here that the atom was split for the first time, the first ever modern computer was built, and graphene was discovered. The University of Manchester is a place where most of the innovations of tomorrow are being researched now.

This report, which results from the contributions of a large number of academics from all of our Faculties and Schools, provides our multidisciplinary vision and approach to address the technological and social transformation the world is currently experiencing. It outlines the challenges that we are currently addressing, and opportunities accessible through our Industry 4.0 capabilities.

Professor Paulo Bartolo
Chair in Advanced Manufacturing
Industry 4.0 Academic Lead
The University of Manchester

Dr Shaden Jaradat
Research Strategy Coordinator
Faculty of Science and Engineering
The University of Manchester

Setting the Scene

Manufacturing is a main factor for the prosperity of nations and an essential source of development and innovation. To guarantee the competitiveness of manufacturing industry, factories have always needed to adapt to new challenges and trends, resulting in several changes of manufacturing paradigms over the last two centuries. Driven by digital tools and technologies, industry is on the threshold of the fourth industrial revolution – Industry 4.0. By enabling the physical and digital worlds to be merged, industrial digitisation has the potential to increase productivity and quality, reduce maintenance costs and time to market, strengthen supply chains, improve resource efficiency and make industry more resilient.

UK Manufacturing is a key part of our economy. It contributes to 10% of GDP, employs approximately 2.7million people, contributes to 45% of exports and accounts for nearly 70% of Research and Development (R&D) investment. Between 2005 and 2016 the UK has dropped from the 5th largest manufacturing nation in the world to the 7th, being overtaken by South Korea and Italy. The sector lacks investment in industrial digital technologies and has a skills gap in its workforce that is inhibiting its drive to increase competitive advantage. Despite a myriad of research and innovation funding schemes aimed at keeping UK universities at the forefront of industrially applicable scientific advancements, UK manufacturers are finding it difficult to recruit people with relevant advanced technical and engineering skills. This difficulty is being further exacerbated by the rate at which new technologies such as digital manufacturing are evolving, and the adoption by manufacturers of new advanced materials to support better productivity.

Nowhere is this mismatch more vivid than the technologies underpinning the fourth industrial revolution. The growing need for integrating automated advanced manufacturing, and the big data it produces, with cloud platforms to enhance performance, will impact business, construction, agriculture and healthcare with far-reaching economic and societal implications.

The need for more investment in industrial digital technologies and the skills gap in its workforce have been recognised by the UK Government. The Made Smarter Review[1] – led by Jürgen Maier, CEO of Siemens UK and an honorary professor at The University of Manchester – concluded that the benefit to the UK economy of adopting Industrial Digital Technologies over the next decade could be as high as £455 billion. In turn, this would lead to growth in manufacturing of up to 3% p.a., create 175 000 jobs in the economy, reduce CO_2 emissions by 4.5% and facilitate the UK's ambition of becoming a world leader in the 4th industrial revolution by 2030.

In the current context, key industrial challenges are related to:

- Modularity: the capability of system components to be separated and easily and quickly combined. System components can be added, rearranged or relocated in the production line on time. Companies should possess high modularity, allowing the rapid integration of modules that can be supplied by multiple vendors;
- Interoperability: the ability to share technical information within system components, including the ability to share business information between companies and customers;
- Decentralisation: system elements (modules, material handling, products, etc.) will make decisions on their own, unsubordinated to a control unit. A decision will be made autonomously in real time without violating the overall organizational goal;
- Virtualization: refers to both creating a virtual factory environment with cyber-physical systems similar to the actual environment and being able to monitor and simulate physical processes;
- Service orientation: companies will shift from selling products to selling products and services;
- Responsiveness: companies must be able to respond to changes on time. Information should be accessed and analysed in real time.

[1] https://www.gov.uk/government/publications/made-smarter-review

National and local government are putting the adoption of digital tools and technologies in UK manufacturing at the heart of their industrial strategies. This report sets out the vision of The University of Manchester (UoM) on the 4th industrial revolution (Industry 4.0 @ UoM), capitalising on our wide range of capabilities which we showcase throughout this document, and bringing together colleagues who are at the forefront of Industry 4.0 from its network of over 800 researchers who are involved in digitisation of technology and society.

OUR VISION

The University of Manchester was born in the epicentre of the first industrial revolution;

We will be at the heart of the fourth.

INDUSTRY 4.0 @ MANCHESTER

Complex social and technical transformation of the world

The use of digital tools and technologies, advanced materials, data and automation for sustainable and smart products, services, and organisations

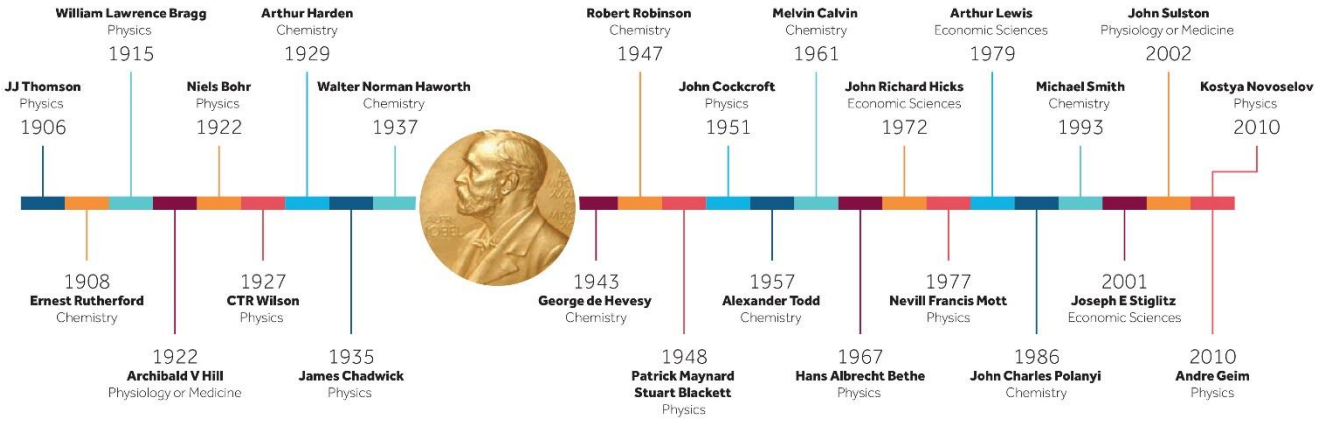
Merging the virtual and physical worlds

Our Aims

- Create a world-leading, self-sustaining Hub for Industry 4.0 solutions in engineering, health and social sciences.
- Forge and strengthen cross-sectorial links with industry and governmental entities.
- Generate opportunities for investment growth through levereged income and industrial partnerships.
- Ensure the next generation of graduates and inter-disciplinary researchers are Industry 4.0 – ready, and attract highly skilled academics and early career researchers in strategic Industry 4.0 areas.
- Promote a vibrant and active research environment, which will foster innovation, create disruptive technologies, new products, and business models and accelerate growth across the value chain for the benefit of society.

The University of Manchester (UoM)

With c.40,000 students, an annual income exceeding £1 billion and 25 Nobel Laureates throughout our history, we are one of the largest, highest ranking and best known universities in the UK. According to the 2018 Academic Ranking of World Universities, we are the 34th best university in the world and the 8th best in Europe.



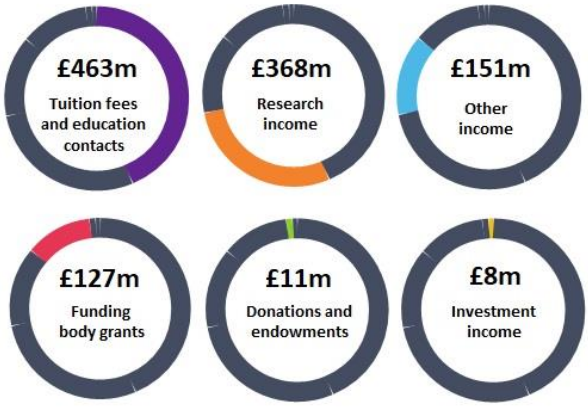
INCOME

We have an annual income of more than

£1 billion.

To find out more about our income and how it is spent, visit:
www.manchester.ac.uk/finances-at-a-glance

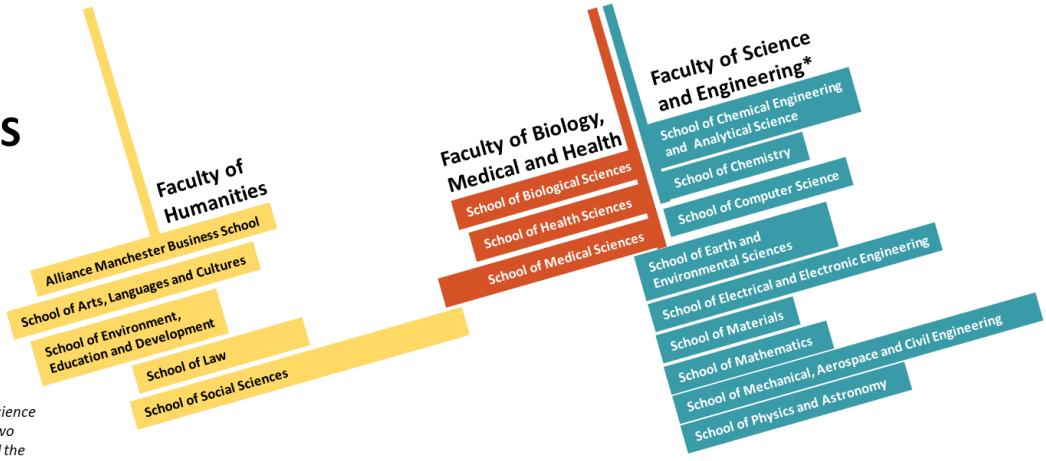
Source: Financial Statements 2018



FACULTIES AND SCHOOLS

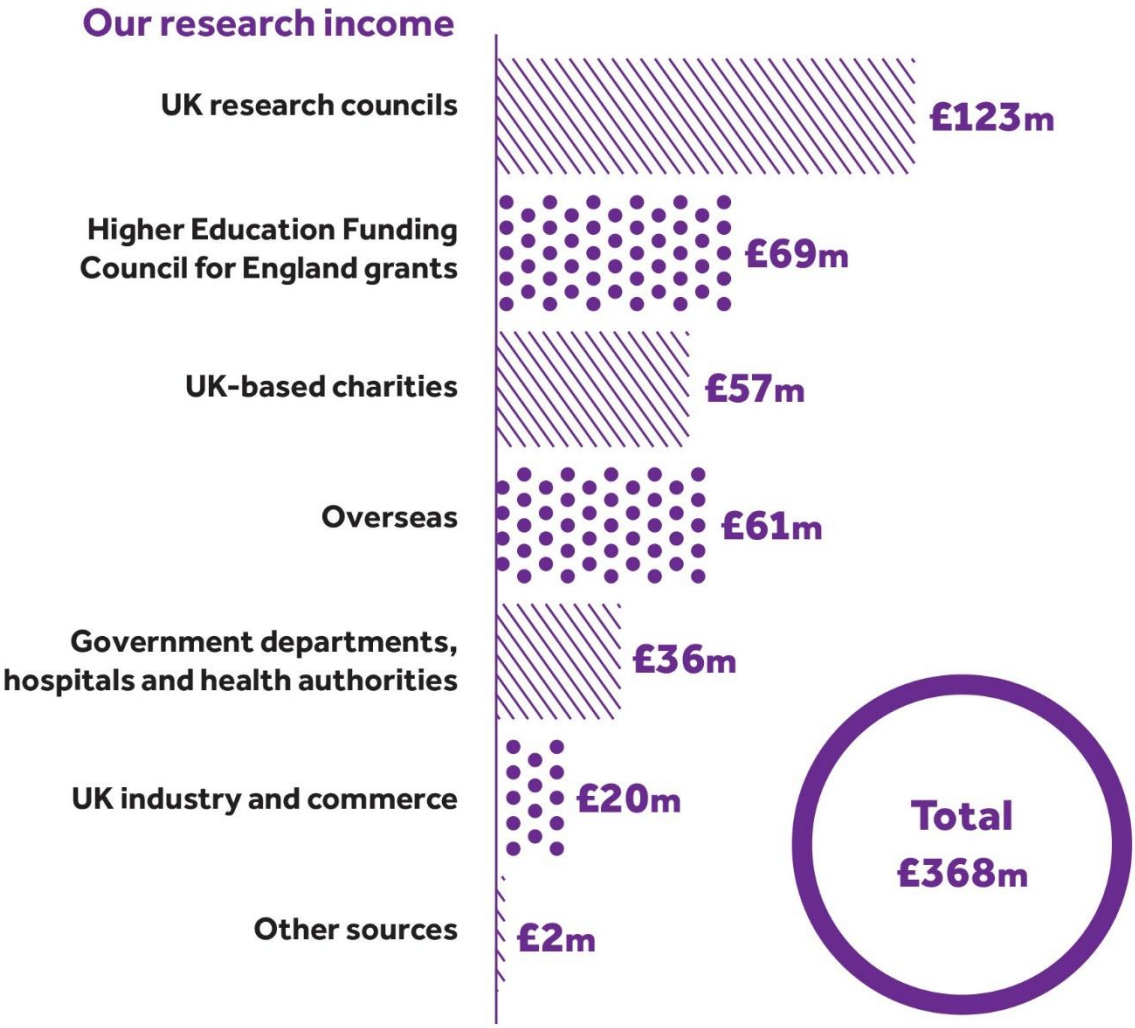
The University is divided into Faculties, Schools, Institutes and hundreds of specialist research groups, all of which undertake pioneering multidisciplinary teaching and research of worldwide significance.

**From 1 August 2019 the Faculty of Science and Engineering will be restricted as two Schools: the School of Engineering and the School of Natural Sciences.*



Our Research Power

In the 2014 Research Excellence Framework 83% of our research activity was rated world-leading or internationally excellent, confirming Manchester as one of the UK's top research institutions.

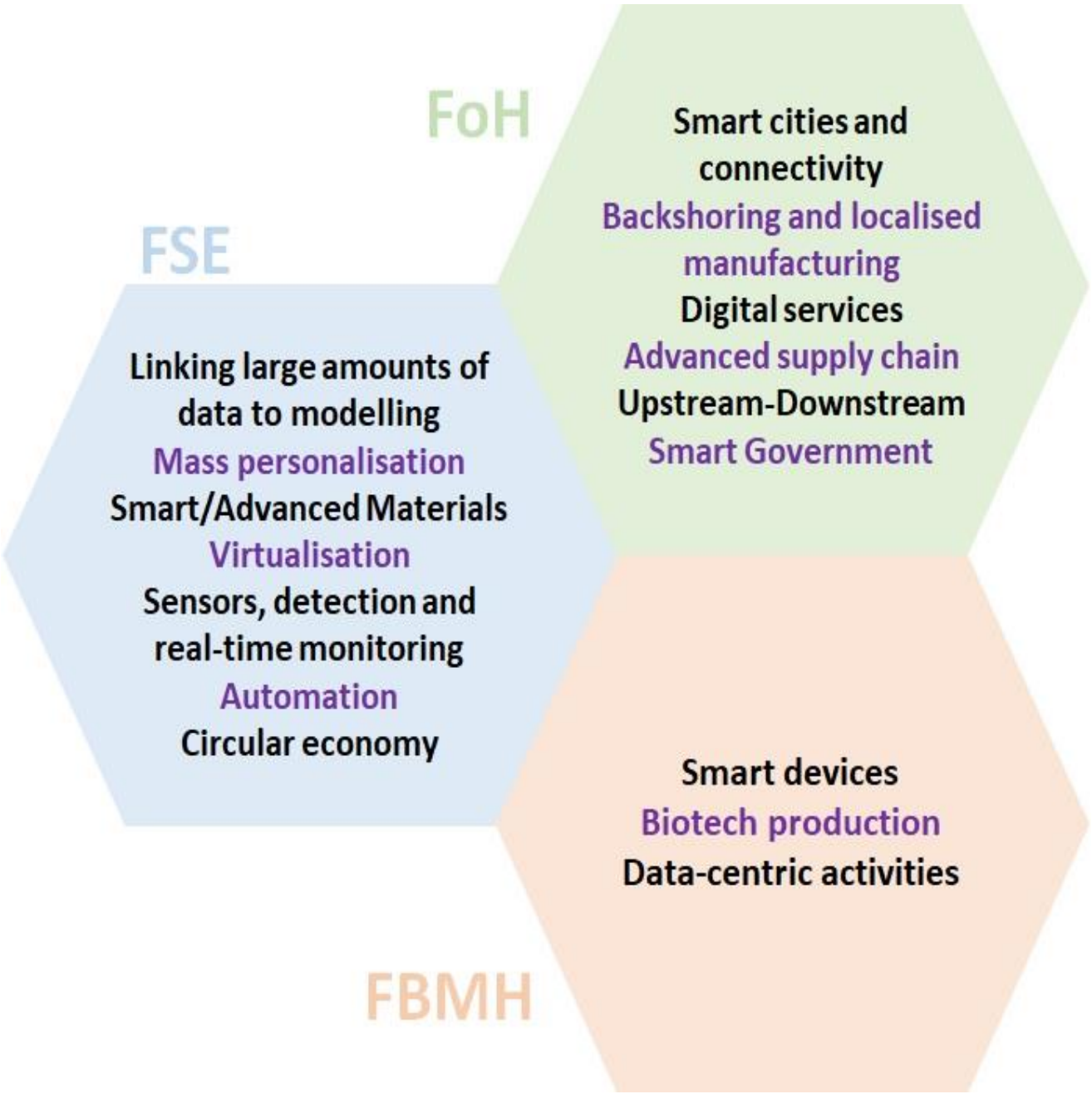


Source: Financial Statements 2018.

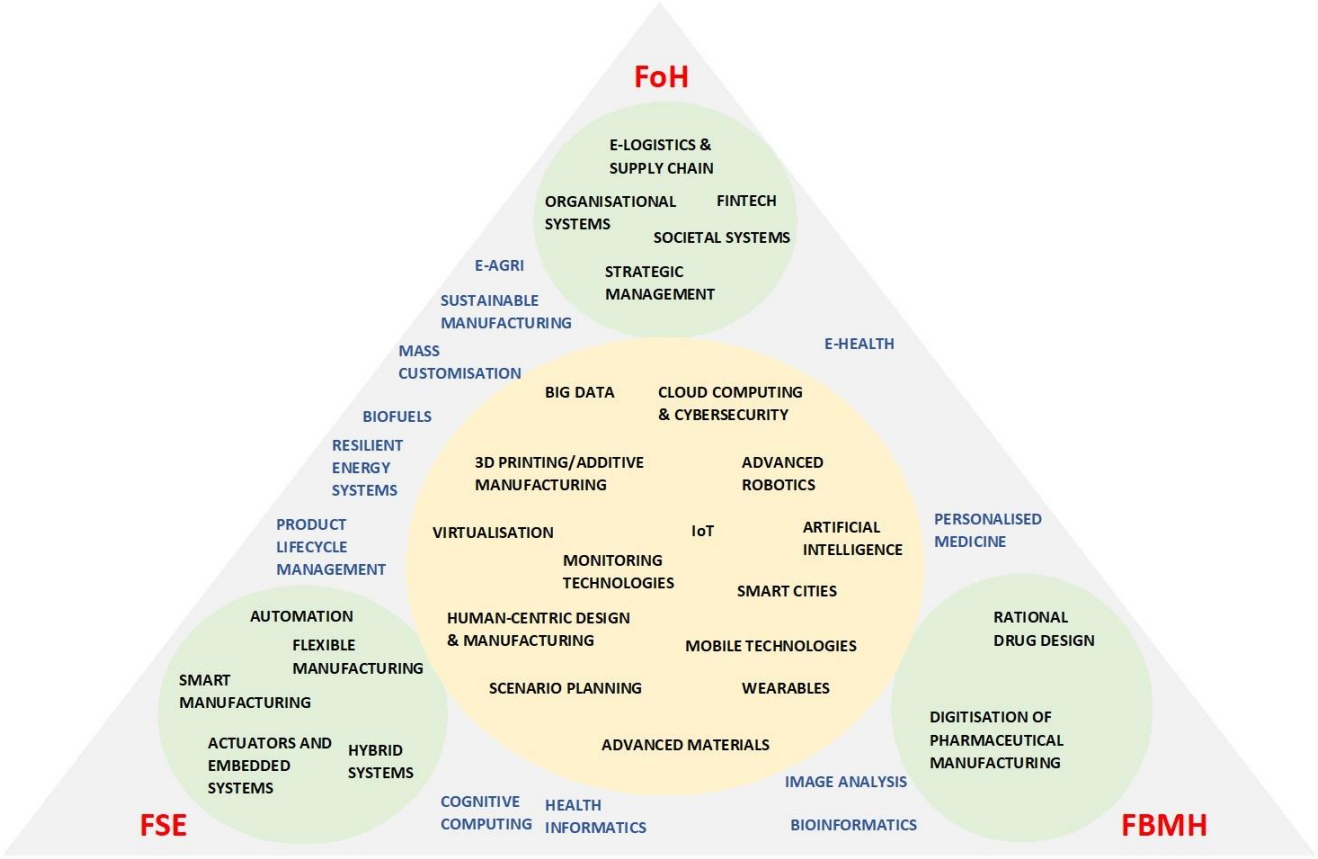
Industry 4.0 @ UoM

UoM Industry 4.0 Perspective

Our three Faculties of Science and Engineering (FSE), Humanities (FoH) and Biology, Medicine and Health (FMBH) have defined Industry 4.0 through the prism of UoM research:



Relying on our Industry 4.0 definitions, our map of Industry 4.0 competences and cross-competences between the three UoM Faculties is based on actual research and business engagement activities conducted by academics in these Faculties.



Our Industry 4.0 Ecosystem

The Industry 4.0 @ UoM Hub will join up our unique ecosystem based on world-class capabilities and infrastructure that enable Industry 4.0.

Manchester Urban Institute

The mission of the Manchester Urban Institute (MUI) is to generate world-class research, achieve high levels of engagement and impact with non-academic stakeholders and train the next generation of urban activists, decision-makers and researchers. By bringing together work from across the arts and humanities, the social sciences, business and health we will create a better understanding of the global urban condition. The vision of the MUI is to realise more inclusive and just cities that are both environmentally and socially sustainable for the current and future generations through world-leading research, engagement/impact and training activities. MUI combines the strengths of existing research centres and groupings from across the university, bringing together the disciplines of anthropology, architecture, arts management, business studies, development studies, education, epidemiology, engineering, human geography, health sciences, history, Latin American studies, planning and environmental management, political science, social gerontology and sociology.

- **Robotics and Artificial Intelligence for Nuclear (RAIN)** is funded by the Industrial Strategy Challenge Fund. The fund is delivered by UK Research and Innovation, and managed by EPSRC. The RAIN Hub brings together eight teams of robotic and nuclear engineering experts from UoM (project lead) and the Universities of Lancaster, Oxford, Liverpool, Sheffield, Bristol, and Nottingham, as well as the Centre for Robotics and Remote Applications in Challenging Environments.

- UoM hosts the **Northwest Composites Centre**, a regional centre of expertise in supporting, evaluating and introducing innovation in manufacture, design, analysis and testing of advanced composites. Its focus is around low cost, energy and cycle time manufacture of composites, non-destructive and structural health monitoring with state- of-the-art X-ray tomography equipment in the **Henry Moseley X-Ray Imaging Facility**. The Centre also houses the National Composites Certification and Evaluation Facility.

- **The Manchester Environmental Research Institute (MERI)** aims to be a world leader in integrated environmental research to address major global, regional and local environmental challenges. Through active engagement with other academic and non-academic stakeholders, MERI seeks to develop holistic solutions for their efficient and effective management, mitigation, and amelioration.

Policy@Manchester

Policy@Manchester showcases the contribution of UoM's researchers to public policy development at home and abroad. Universities like Manchester act as important sources of knowledge, expertise and research for policy makers. However, as it is such a large organisation, finding the expertise needed – and quickly – can be a challenge. The Policy@Manchester initiative works to connect researchers with those working on policy, supporting and smoothing the process of knowledge exchange where needed. It is also a platform to find and share ideas on the big issues facing us today, whether that is through events, blogs or publications.

Sir Henry Royce Institute for Materials Research and Innovation

Bringing science together with business applications to address societal challenges, it operates as a hub and spoke model, with the hub at UoM, and spokes at the Universities of Sheffield, Leeds, Liverpool, Cambridge, Oxford and Imperial College London.

Case Study: Science-industry-government collaboration wins initial support for Mersey Basin proposal

The "Mersey Basin" collaboration has won £50,000 seed funding from the Government's Industrial Strategy to help develop a full bid for up to £50 million. The project focusses on the M56/M62 corridor, stretching from the Liverpool City Region to Manchester, which has a high concentration of materials-based companies and significant numbers of small-and-medium sized companies. The project will link the region's world-class facilities in new materials, digital manufacturing, high performance computing and artificial intelligence to help companies improve the use of new techniques to boost productivity and create jobs. It would focus on five materials sub-sectors: sustainable solutions in fast moving consumer goods and packaging; smart coatings and sensors; energy; medicines/biofilms; and advanced manufacturing. Funding is provided through UKRI's Strength in Places Fund, established as part of the Industrial Strategy. Final bids will be submitted in late 2019. The project partners include UoM, the Henry Royce Institute, the Hartree Centre at Daresbury, IBM Research, the Alan Turing Institute, and the University of Liverpool.

- **BP International Centre for Advanced Materials**, centred in UoM with satellites in the University of Cambridge, Imperial College London and the University of Illinois at Urbana-Champaign, which leads advanced materials research into fuels for the oil and gas industry back into business operations, understanding impacts around safety, reliability and performance.

- **The Thomas Ashton Institute** is a collaborative partnership between the Health and Safety Executive and The University Manchester. It is an interdisciplinary research institute concerned with the understanding of failures that occur in the workplace leading to injury or ill-health.

- **The Tyndall Centre** brings together natural scientists, engineers, social scientists and economists to produce socially impactful and policy-relevant interdisciplinary research. Its work includes: energy systems resilience, lifecycle assessment, carbon budgets and pathways, the water energy food nexus, the circular economy and stakeholder and public engagement with sustainability issues.

- **The Manchester Data Science Institute** The University's Data Science Institute has an engaged data science community of over 600 investigators, with methodologists addressing problems in extracting meaning from data, managing data volume, the variety of data used in analyses, the velocity with which it is produced and the veracity of those data. We are a partner in the national Alan Turing Institute for Data Science and AI, and we carry out world-class research in computational statistics, machine learning, visual computing, advanced interfaces and information management.

- **The Aerospace Research Institute** is an innovative, cross-disciplinary research institute focusing on emerging aerospace challenges to enhance the UK's position in the global aerospace market.

Digital Futures

Digital Futures brings together over 850 researchers from different disciplines across all three of the University's faculties into multidisciplinary communities to tackle important research problems posed by the great issues facing the world in the 21st century. Digital Futures is built around societal challenges (including Work & Employment, Cities & the Environment and Industry 4.0) and focusses on our cross-cutting capabilities (including Data Science & AI, Digital Trust & Security, IoT and Human Centred Design). We are able to combine disciplines and capabilities to meet both the challenges of leading-edge research and the external demands of government, business and communities. See: www.digitalfutures.manchester.ac.uk

Impact and Adoption of Industrial Digitisation Technologies

We have a track record of partnerships that create innovation through the use of new technologies.

In their quest for improving profits, productivity, flexibility, quality, time-to-market, and the working environment, public and private sectors seek collaboration in a wide range of areas such as processes development, monitoring and integration, advanced materials, human-centric design and manufacturing, and new business models. UoM has a track record in innovative research, generating high-impact outcomes as well as adoption-ready Industrial Digitisation Technologies (IDTs).

CAFE4DM: Example of UoM-Industry Partnerships

Centre in Advanced Fluid Engineering for Digital Manufacturing, CAFE4DM (£6.1 million), jointly funded by Unilever, UoM, Cambridge University, EPSRC and STFC aims to address the challenges in understanding, creating and scaling up manufacturing processes for formulated products in fast moving consumer goods (home/personal care and food products). The main objective is to develop a new modelling approach and the associated materials, measurement and validation to describe these mixtures to enable a significant reduction in conventional physical experimentation.

A decision support system for treatment adherence monitoring in chronic diseases
Our prototype software performs adherence monitoring based on the pharmacokinetics of the treatments recorded by users using smartphones. Our software, ideally suited for chronic diseases, has been designed and developed using Haemophilia treatment data provided by Medical Data Solutions and Services (a NW SME). The innovative prototype can rank patients based on compliance, send email and SMS alerts when prescriptions are not followed and provides an interactive graphical interface to its users. Future work will seek to gather more treatment data, and to develop machine learning models to predict adverse effects and recommend personalized treatment prescriptions.
Prof John Keane

Smart Robotics in Nuclear Decomissioning
This project explores the use of soft robotics for inspection of hazardous nuclear environments in collaboration with National Nuclear Laboratory. Soft robotics has many advantages over traditional (non-flexible) robots in that they can be designed to bend around multiple obstacles and move through narrow spaces without causing damage. The materials the robots are made from are low cost and can be easily manufactured. Soft robotics may be more suitable than mobile robotic systems for inspection operations as they are inherently retrievable unlike mobile platforms. This under-explored technology has the potential to enhance and compliment capability whilst reducing costs.
Dr Andrew Weightman

Autonomous in-field detection of crop traits and stress sources
The e-Agri team, within the School of Electronic & Electrical Engineering, have been integrating modified imaging sensors and light manipulation to identify and detect in a real-time, non-invasive manner, food-crop traits (e.g. drought tolerance, expression of sugars, etc.), species (e.g. early emergence of weeds) and pests (e.g. virus carrying insects) as well as the sources of abiotic (e.g. temperature, nutrient deficiency, etc.) and biotic (e.g. fungal, bacterial, etc.) stresses. This technology is designed to operate as the front end to autonomous and robotic field management machinery and is based on machine learning approaches. The technology is now forming part of a next generation weed control strategy, with a multinational agribusiness as well as broader set of related products, from a University spin-out, which address crop ripening, contamination and vertical farming control at an industrial scale.
Prof Bruce Grieve

Multimodal Interfaces for Robot Companions
Social robots are being increasingly designed as robot companions for health and social care. As these robots have to communicate and interact with people, the consideration of people's preferences and acceptability and trust of the technology is crucial. We have developed and tested multimodal interfaces for robot companions for the elderly. These on purpose include multiple, redundant communication modalities (e.g. speech, tablet, gesture recognition) following on experimental studies with older people to test their preferences and task-specific requirements. In addition, we have demonstrated that trust in human-robot interaction can be increased when controlling some of the robot's behavioural strategies (e.g. gaze).
Prof Angelo Cangelosi

Data-driven design an optimization of biopharmaceutical manufacturing processes
This case study describes a collaborative project between UoM and a consultancy company specialising in modelling drug manufacturing processes. The objective of the project was to extend an existing simulation model for manufacturing processes with a flexible data-driven optimization tool capable of creating autonomously manufacturing processes that meet user-specified objectives in terms of, for example, cost-efficiency, process robustness, environmental impact, and facility footprint. The project is funded by Innovate UK and the outcome so far is a prototype software that is currently being tested by various clients in the pharma sector. Commercialisation of the new simulation-optimization tool will commence following testing.
Dr Richard Allmendinger

AVEXIS
We developed a proof of concept submersible robot that was able to be deployed through a 150 mm access port. The robot was successfully demonstrated in a large pond that simulated the 100 m long ponds found on the Sellafield site. Following the successful demonstration the robot was commercialised by an SME in Cumbria, Forth Engineering. The submersible robot has since been deployed into the Magnox Swarf Storage Silo on the Sellafield site, regarded as the most hazardous facility in Europe. An offshoot of the work has led to the development of a second robot that has been developed specifically for deployment into the Fukushima Daiichi reactors and this has been successfully demonstrated at the Fukushima remote operations research centre.

Prof Barry Lennox

ARTEMIS: Using Virtual Reality to Improve the Ease of Scientific Model Building
The ARTEMIS immersive virtual reality (VR) tool is being developed to allow scientists to build theoretical models using hand gestures and virtual objects. The user focuses on the science and concepts, while the distraction of mathematics and code are minimized. A simple prototype to create Feynman particle interaction diagrams using virtual objects, which then generate the corresponding model equations, was created. This idea is being upscaled to a demo version using neutrino physics models. Professional VR developers are also being sought to prototype a version using augmented reality technology suited to multiple users collaborating on the same model in real-time.
Dr Bernadette Cogswell

Influence of network correlation structure in multivariate time series forecasting
The interdependent relationships between multiple time varying variables, such as stock prices, have been increasingly studied over recent years. In this study we provided a state-of-the-art methodology based on Network Analysis to better understand the evolution of complex interdependent relationships between multiple variables over time. Our methodology uses the comparison of the interdependent structure of variables in the present, to the ones observed in the past. Then, the previous times with closest structures are used to provide a weighted average forecast. We applied our methodology to 'the Standard & Poor's 500' stock market index; and a Bank of England's macro-economic data-set. We found that our methodology produces better results than a ``Buy and hold'' strategy, and that it has the potential to further improve multivariate time series forecasting. It also provides a simple way to identify early warnings signs of critical changes in the interdependent structure of the system.
Dr Luis Ospina-Forero

Remote characterisation with robotics for harsh environments

Remote characterisation of chemical and radiological environments using advanced robotics is an approach based on NASA's Mars Curiosity Rover whereby modular analytical sensors such as Raman spectroscopy for molecular systems, Laser Induced Breakdown Spectroscopy (LIBS) for elemental analysis alongside radiation sensors combined with standard low cost sensors are mounted on a mobile robot platform. The characterisation data is combined with spatial mapping such as by robot-mounted Light Detection and Ranging (LIDAR) to provide an important visualisation tool for systematic surveying of harsh environments where human access is difficult. This approach has potential application in a range of sectors.

Prof Philip Martin

Interpretable Machine Learning for Fraud Detection, Risk Assessment and Fault Diagnosis

This case study is to investigate the application of a novel interpretable machine learning methodology to assess risk, detect fraud and diagnose fault. The methodology makes a hybrid use of statistical data analysis, extended Bayesian inference, rule-based probabilistic modelling and maximum likelihood machine learning. The primary data and knowledge of the case study come from car insurance industry where fraudulent claims are a major concern. The methodology can take into account both big data and human judgement to support evidence-based decision making. The applications of the methodology have also been in healthcare, financial technology, new product development and system maintenance.

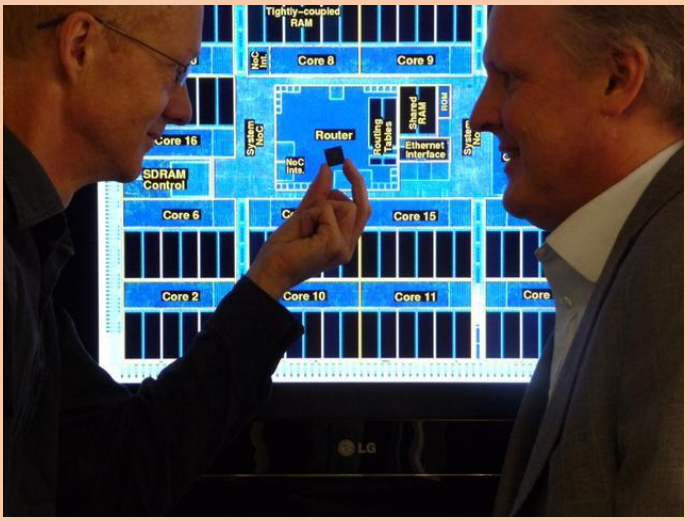
Prof Jian-Bo Yang

Dataviewer — Data Visualisation Software

Dataviewer is the result of collaborations between UoM, Rutherford Appleton Laboratory and local SMEs Cake Solutions and The Start-up Factory. A combination of industrial studentships, undergraduate placements and Impact Acceleration funding has produced a fast software solution for visualising large multivariate data sets. Visual aids highlight key variables and guide users in exploring and understanding multi-dimensional data. The software is not specific to any single data type, allowing a wide range of applications. The company Dataviewer Ltd was incorporated in 2016, with potential applications in financial markets, drug discovery and testing, industrial biotechnology manufacturing, bioinformatics and retail.

Prof Steve Watts

Spiking Neural Network Architecture (SpiNNaker)



The world's largest neuromorphic supercomputer designed and built to work in the same way a human brain does. The newly formed million-processor-core machine is capable of completing more than 200 million million actions per second, with each of its chips having 100 million transistors. To reach this point it has taken £15million in funding, 20 years in conception and over 10 years in construction. The SpiNNaker machine, which was designed and built in UoM's School of Computer Science, can model more biological neurons in real time than any other machine on the planet.

More info can be found here: http://apt.cs.manchester.ac.uk/projects/SpiNNaker/project/

Prof Stephen Furber

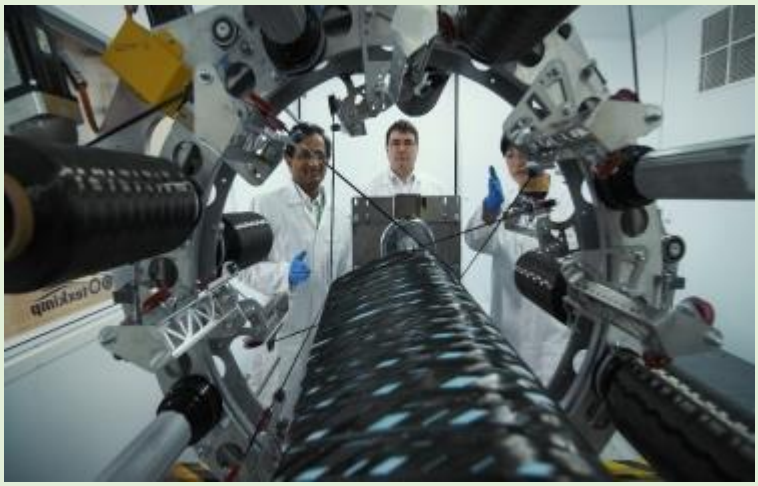
AI/ML for optimising patient transport in health & care
A partnership between 365 Response and the Decision and Cognitive Sciences Research Centre of Alliance Manchester Business School to develop new tools to improve transport flow and resource utilisation across health and care to improve quality of care for service users and efficiency for providers. This project will enable 365 Response to build the first automated intelligent system to optimise whole-system health and care transportation services. The system will allow, for the first time, to make full use of the large amount of historical data available. The resulting insight will pave the way towards an advanced level of forecasting and planning capability that cannot be achieved with the software / workforce currently available.
Dr Manuel López-Ibáñez

Surface modification and coating of AM parts
UoM has expertise in the coating and surface treatment of additive manufactured (AM) products- particularly in titanium, aluminium, nickel and ferrous alloys. Control of the coating surface finish and performance is a key element to be able to define a product's digital twin. The techniques used are based on environmentally friendly plasma-assisted processes and include methods to harden, convert (eg oxide or nitride) or coat the surface. Additionally, techniques have been developed to polish AM surfaces. All of these methods can extend the wear and corrosion lifetimes of AM products, as well as improve their fatigue performance.
Prof Allan Matthews

Developing a groundbreaking 3D winding machine for the global automotive and aerospace industries
Cygnet Texkimp, a specialist machinery manufacturer for the global aerospace, automotive, wind energy and industrial markets, collaborated through a Knowledge Transfer Partnership (KTP) with specialists at the University's School of Materials to develop a solution for one of the largest gaps in the composites market: how to create complex components cost-effectively, in high volumes, and at high speeds.

Extending the work of a 9-Axis robotic winding concept first developed by Professor Prasad Potluri, the partnership created the world's first robotic 3D winding machine capable of making complex parts for the global automotive and aerospace industries. As well as enhancing Cygnet Texkimp's product offering with new filament winding technologies, the project has delivered many offer benefits, including the permanent employment of the KTP Associate into Texkimp's R&D Centre and receiving the prestigious Composites UK award for Innovation in Manufacturing.

"Creation of a new product stream in the speed that we've done it is a direct result of working with the University and the KTP programme to develop this new technology."
Luke Vardy, Managing Director, Cygnet Texkimp



"The composites industry is waiting for technologies that would significantly reduce the cost of production, and this technology will contribute to such an effort where we can mass-produce composites."
Professor Prasad Potluri, School of Materials, The University of Manchester

Dynamic binary translation for virtualisation

Binary translation enables applications compiled for one architecture to run on another. Research on dynamic binary translation was commercialised through the spin-out company Transitive in 2000. Transitive employed 80 staff at its engineering lab in Manchester and delivered over 20 million copies of its software, before being acquired by IBM in 2009, giving rise to the IBM Manchester Lab. Transitive technology was fundamental in Apple's transition to Intel CPU chips, and was shipped with around 14 million Mac computers between 2008 - 2014. The technology was described as "The most amazing software you'll never see" by Steve Jobs.

Nanoco Group Ltd

Nanoco, is a UoM spin out company with a market capitalisation of over £350m. Nanoco's proprietary processes enable, for the first time, commercial quantities of high-quality quantum dot nanoparticles, free of toxic heavy-metals, to be manufactured economically – for incorporation into next-generation displays & solar-cells.

As a result of its world-leading disruptive technology, Nanoco has forged down-stream global business partnerships that have generated over £10m revenue, creating more than 90 jobs with Nanoco (at a cost of over £3m/year), substantial secondary employment in the supply chain, and underpinning technology to enable the delivery of more energy-efficient electronic devices.

Organic Materials Innovation Centre (OMIC)

The activities of the Organic Materials Innovation Centre (OMIC) at the UoM generate impact from its research activities through knowledge transfer to industry. This is exemplified by:

- Enabling UK SME ACAL Energy, through technology transfer and development, to create in excess of 20 jobs, raise £15m of venture capital investment to develop their FlowCath® fuel-cell technology.
- Enabling UK SME Byotrol, through improved understanding to develop novel anti-microbial technology which has been licensed to global fast moving consumer goods companies with sales of £2.19m per annum.
- Provision of research-based training in the field of printed electronics and sensors to over 250 people from 2008 onwards.

The University of Manchester Intellectual Property – UMIP®

UMIP® are catalysts for innovation, responsible for intellectual property commercialisation and technology transfer of next-generation technologies which are developed by UoM's world-class, innovative research base. Our job at UMIP is to turn these innovative ideas into commercial reality. In doing this we help to boost research and development, stimulate the economy and create jobs. As a result of the high commercial impact of its patents, Manchester is ranked in the UK's top three most innovative universities according to Reuters Top 100 Most Innovative Universities 2018.

Opportunities

International Landscape

Recognising the importance of manufacturing to their industrial future, different countries have already launched programmes to support the deployment of technologies and policies that are key to propelling Industry 4.0. A large number of these programmes, particularly in the developing world, align with UoM's Industry 4.0 competences, thus offering an opportunity for active capacity-building partnerships in areas such as: industrial digitalisation; advanced materials; robotics and advanced manufacturing systems; resources, energy efficiency and decentralisation of energy production; human capital; health and quality of life.

The Global Challenges Research Fund (GCRF)

Following the submission of a three-year strategy, Research England has awarded the UoM £2.3 million a year to support projects seeking to address sustainable development goals in developing countries. This fund will enable researchers to apply for funding to tackle complex global problems associated with areas identified by UKRI, many of which are relevant to Industry 4.0 including:

- Sustainable health and wellbeing;
- Sustainable livelihoods supported by strong foundations for inclusive economic growth and innovation;
- Sustainable cities and communities;
- Sustainable production and consumption of materials and other resources.

"It gives me great pleasure to reconfirm the University of Manchester's complete support for and commitment to our Industry 4.0 strategy, which combines the best elements of our well recognised interdisciplinary approaches to addressing global challenges. Current projects combine engineering, advanced materials, physical, biomedical and data sciences to focus on societal problems worldwide."
Professor Stephen Flint – Associate Vice President for Internationalisation, The University of Manchester

Examples of UoM's Global Industry 4.0 Engagement

Trials in Ethiopia Paving the way Towards a Real-time, Low Cost In-field 'Bio-Mimic' Sensor Network for Wheat Stripe Rust Disease in the Africa Plant Health Initiative

The aim is to accelerate the impact and deployment of a bio-mimic crop disease sensor, using bio-sensitive materials and additive manufacturing and then testing at four Ethiopian Federal and Regional government research stations for trials with African scientists. This will be the first demonstration of the core component in an accurate, ground-truthed, real-time monitoring and defence network for fungal epidemic control across Sub-Saharan Africa and will have direct implications on Manchester being invited into a larger Gates Foundation and GCRF programme for the Africa Plant Health Initiative.

Leads: Prof Bruce Grieve and Prof Paulo Bartolo

Indonesia Industry 4.0 Project

This project focuses on helping Indonesia move its manufacturing to Industry 4.0 levels. UoM provided training and envisioning workshops for CPD in collaboration with the Institute of Technology Bandung. Additional project partners, PT INKA (national train manufacturer) and the British Council enabled the project team to run a pilot project to improve air conditioning manufacturing and to propose new training programs to make Indonesia 4.0 ready to DIKTI (ministry of education). From the project PT INKA will now try to implement Industry 4.0 principles in other areas of its manufacturing.

Leads: Dr Glen Cooper (UoM) and Dr Sri Raharno (Bandung Institute of Technology, Indonesia)

Urban IoT in Informal Settlements in the Global South

The project examines how Internet of Things (IoT) technologies are being applied to improve life in informal settlements in the Global South. The project focuses on three cases in Nairobi, Kenya: smart metering for community water tanks, an automatic ATM-style water dispenser and smart metering for LPG cylinders. Interviews with users, providers and senior stakeholders shows how IoT technologies are establishing trust between users and providers as well as improving the reliability of service provision. For example sensors in water tanks let residents know via mobile phones where water is available saving considerable time spent walking and queueing. In this way IoT technologies are providing residents in informal settlements increased certainty, which enables them to plan daily activities more effectively and achieve personal economies. The project identifies the huge potential to engage with the potentialities of IoT technologies and Industry 4.0 more generally beyond wealthy urban settings in the Global North.

Leads: Prof James Evans and Doctoral Researcher Joe Chambers

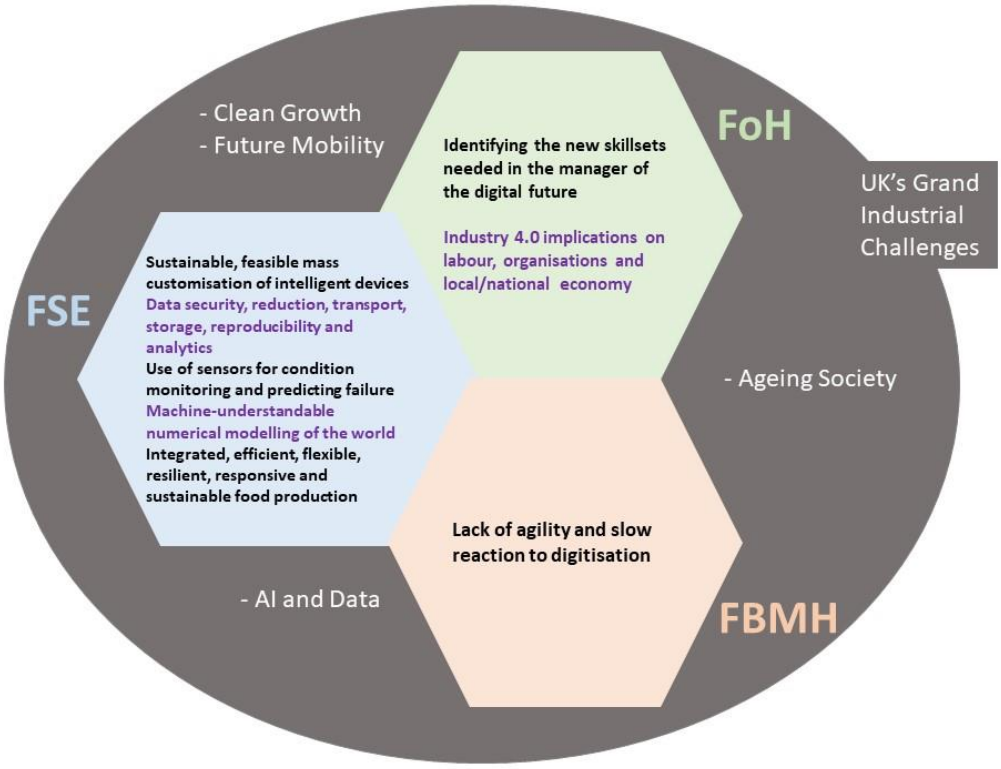
How data collected from mobile phones can help electricity planning

UoM researchers have used mobile phone data to develop a countrywide electrification strategy for Senegal, where access to electricity can be woefully low. In order to design the best systems, planners must ascertain where on- or off-grid systems should be placed, their size and what type of energy should be used for the most effective impact. However reliable data is scarce. Our researchers found that mobile phone data provides vital information such as how many people there are in an area, electricity demand and distance from the closest electricity grid. Different electrification options – such as solar energy use - can then be costed and the cheapest one selected.

Leads: Eduardo Alejandro Martínez Ceseña, Joseph Mutale, Mathaios Panteli, Pierluigi Mancarella

National: Made Smarter

The Industrial Strategy Challenge Fund (ISCF) aims to bring together the UK's world-leading research with business to meet the major industrial and societal challenges of our time[2]. This is part of the government's commitment to raising total R&D investment to 2.4% of GDP by 2027, manifested in the 2018 Autumn Budget[3] by an additional £1.1 billion allocated to ISCF, including £147 million over a period of five years to support the transformation of manufacturing through digitally-enabled technologies. The Made Smarter themes align with the Industrial Strategy's 4 grand challenges (AI & Data, Ageing Society, Clean Growth, and Future Mobility)[4].



The Industry 4.0 Challenges mapped by UoM researchers against the four Grand Industrial Challenges

[UoM has] the knowledge and expertise to be able to support projects within [the Made Smarter] themes: Smart Connected Factory; Connected and versatile supply chain; Design, make, test; and Adaptable, flexible manufacturing operations and skills. The University of Manchester is keen to support this programme through collaborative research and development projects or any relevant engagement within the programme framework.
UoM letter of support to Made Smarter, February 2019

[2] https://www.gov.uk/government/collections/industrial-strategy-challenge-fund-joint-research-and-innovation
[3] https://www.gov.uk/government/publications/budget-2018-documents/budget-2018
[4] https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges

Regional Opportunities

Greater Manchester is a world-renowned centre of industry, enterprise and innovation. It is also one of the most diverse city region economies in the UK. The largest sectors in terms of employment and number of businesses are the Business, Financial and Professional Services (24% of total business), Wholesale and Retail (21%), Construction (10%), Digital and Creativity (9%), Hospitality, Tourism and Sport (8%), Manufacturing (7%) and Logistics (7%). Moreover, around 83% of businesses are micro-sized (employing 0-9 people), 13% small (10-49 people), and 3% are medium-sized (50-249 people). There are 570 large business (250+ employees) accounting for under 1% of the business base.

"The UoM proposition around Industry 4.0 aligns seamlessly with the Greater Manchester Industrial and Digital Strategy. Technology and innovation in fields such as AI, robotics, additive manufacturing, virtual & augmented reality, the Internet of Things, and the convergence of these technologies, can make a considerable impact on increasing the competitiveness of the manufacturing industry. The city is developing expertise in areas such as cyber security and robotics, positioning it as a key location for companies developing Industry 4.0 technologies and with access to significant market opportunities."

Tim Newns, CEO, MIDAS – Manchester's Inward Investment Agency

Greater Manchester has the aspiration to be one of the cleanest and greenest city regions in Europe. Green technologies and services employ 45,000 people across 2,400 companies. These fit with our UoM and GMCAs research strategy to promote the design and development of new flexible, distributed, manufacturing facilities integrated in an urban environment; to develop scientific breakthroughs to enable personalised products to be produced locally in a resource and energy efficient manner with a view to realising a zero-emission manufacturing environment; and to enable the evolution of suburban factories to operate effectively in the urban environment they are now in. Examples of relevant UoM-led, UKRI-funded projects in this space include **Rethinking resources and recycling** (£820k), **Research on the theory and key technology of laser processing and system optimization for low carbon manufacturing** (£813k), **Rebuild – regenerative buildings and products for a circular economy** (£1273k) and **New industrial systems: manufacturing immortality** (£2192k).

"We will continue to work closely with key regional players such as the Greater Manchester Combined Authority (GMCA), MIDAS (Manchester's inward investment agency) to ensure our Industry 4.0 @ UoM Vision & Strategy is aligned with the evolving scope of Manchester's priorities as set out in the Independent Prosperity Review and the Local Industrial Strategy."

Prof Paulo Bartolo, UoM Industry 4.0 Academic Lead

Teaching and Learning

"Studying at university can and should be a unique and transformational experience. It should challenge your principles, take you outside your comfort zone, broaden your horizons and deepen your awareness, give you opportunities to grasp new experiences — often abroad — and even expose you to some shocking realities through volunteering in areas that you may never have known. There are opportunities to learn about so many things outside your chosen subject or discipline. Employers repeatedly tell us they want graduates equipped with more than a good degree result; and society needs engaged, informed and questioning citizens."

Professor Dame Nancy Rothwell, President and Vice-Chancellor of The University of Manchester, writing in the Financial Times

The University College for Interdisciplinary Learning (UCIL) introduces students to new topics and ways of thinking, tackling the key questions facing society in the 21st century - for example, the digital revolution, globalisation and mental health. Our units equip them with invaluable knowledge and skills which will complement their studies and make them more employable. It provides a unique learning experience by giving students the chance to meet and study with students from different degree programmes across the University. They are taught by the same academic staff who teach discipline-based programmes. UCIL will be our vehicle for enhancing the Industry 4.0 – compatibility of the teaching and learning experience of our students.

Industry 4.0 Inspired Units

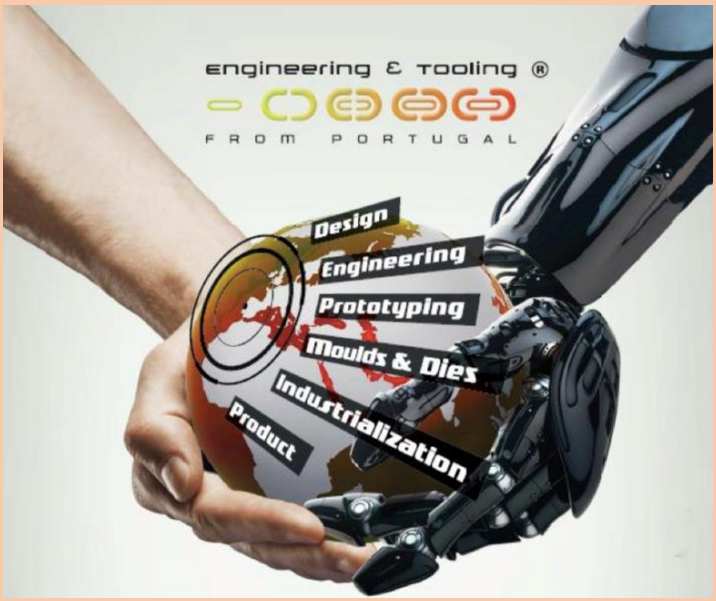
The Information Age
Delivered by: Centre for the History of Science, Technology and Medicine
This unit uses historical case studies to show how and why digital information processing occupies a crucial role in present-day life. Combining strands from technical, social, cultural and economic history; it describes the development of mass-produced computer technology and mass public access to information systems, and their consequences for society. It will also show the role of hopes, fears and other visions in informing public ideas, using examples ranging from employment forecasting to science-fiction dreams.

AI: Robot Overlord, Replacement or Colleague?
Delivered by: School of Computer Science and School of Health Sciences
This unit will demystify AI, explaining how it works, and demonstrating its limitations. Its overarching aim is to equip Manchester graduates from all disciplines with an understanding of the impact this technology currently has, the way this is likely to change in the future and, crucially, the ability to grasp the opportunities it brings, whatever your chosen career.

Digital Society
Delivered by: UoM Library
In this unit, you will explore your place in the digital world, the connectedness of digital life, the relationship between the individual and the state, the smart cities of the future (and now), ethics of the online world and the impact of digital and mobile technology on business and marketing. This unit aims to explore the relationship between digital technology, society, and you - from the connectedness of our lives and the machines around us, to how we communicate with each other.

UoM has c. 12,000 students in STEM subjects, nearly a third of whom are in postgraduate degrees

CPD Example: Human-Centric Manufacturing



This CPD course, delivered to Pool-Net (the Portuguese Tooling and Plastics Network Association), aims to facilitate high-level strategic discussions on how best to capitalise on human-centric manufacturing in the emerging context of Industry 4.0. The CPD covers emerging social-technical trends, the changing role of creativity and innovation in manufacturing, human capital development, and leadership in a changing world context.

The tooling (mouldmaking) industry is one of the most dynamic industries in Portugal, playing an international leading role by exporting 90% of its production. It is a major tool supplier of large multinationals (from automotive, aerospace, electronics, home appliances and packaging industries), being equipped with state-of-the-art technology including additive manufacturing and laser manufacturing. Pool-Net is a key player in the Portuguese Industry 4.0 initiative, focusing on design for manufacturing and zero-effect manufacturing. It plays also a key role on establishing Strategic, Technological and Business Partnerships on a global scale.

UoM Delivery Lead: Professor Paulo Bartolo

Our Proposition

Our Industry 4.0 Hub is at the centre of a vast network of researchers and external contacts, all keen to collaborate to capitalise on regional, national and international opportunities

Enabled by dedicated resources in the Hub, we are creating a joint academic & industrial Steering Committee. Its roles include:

- Identifying the priority Industry 4.0 challenges and the means to address them through the lens of UoM's interdisciplinary strengths and industrial partnerships.
- Maintaining a UoM-Industry consortium that is agile and able to respond rapidly to emerging funding opportunities.
- Advising on the scope and objectives of collaborative teaching & learning activities aimed at ensuring students and trainees are Industry 4.0 - Ready.

Our Industry 4.0 Innovation Lab will provide stimuli for joint, innovative incubation projects:

- These will sow the seeds for larger, strategic, externally funded projects with our industry partners addressing the priority Industry 4.0 challenges.

"Innovation Labs provide an effective and robust platform to get a number of diverse sectors and industry representatives in one room to address real challenges in Industry 4.0 and co-develop research projects with multidisciplinary academics. The seed corn funding awarded to promising projects is a stepping stone to establish cross-disciplinary relationships that can be leveraged for various follow-on activities."
Dr Richard Allmendinger, Lecturer in Decision Sciences, Business Engagement Lead at the Alliance Manchester Business School and Principal Investigator for the Industry 4.0 Innovation Lab

We will create a suite of University College for Interdisciplinary Learning units that will form a model for the future of Industry 4.0 - compatible university programmes:

- Our Industry 4.0 teaching and training will reflect the highly interdisciplinary spectrum of our Industry 4.0 research and capabilities

We will work with internal networks as well as external partners to develop policy propositions for local and national government to facilitate partnerships between academia and leading Industry 4.0 players.

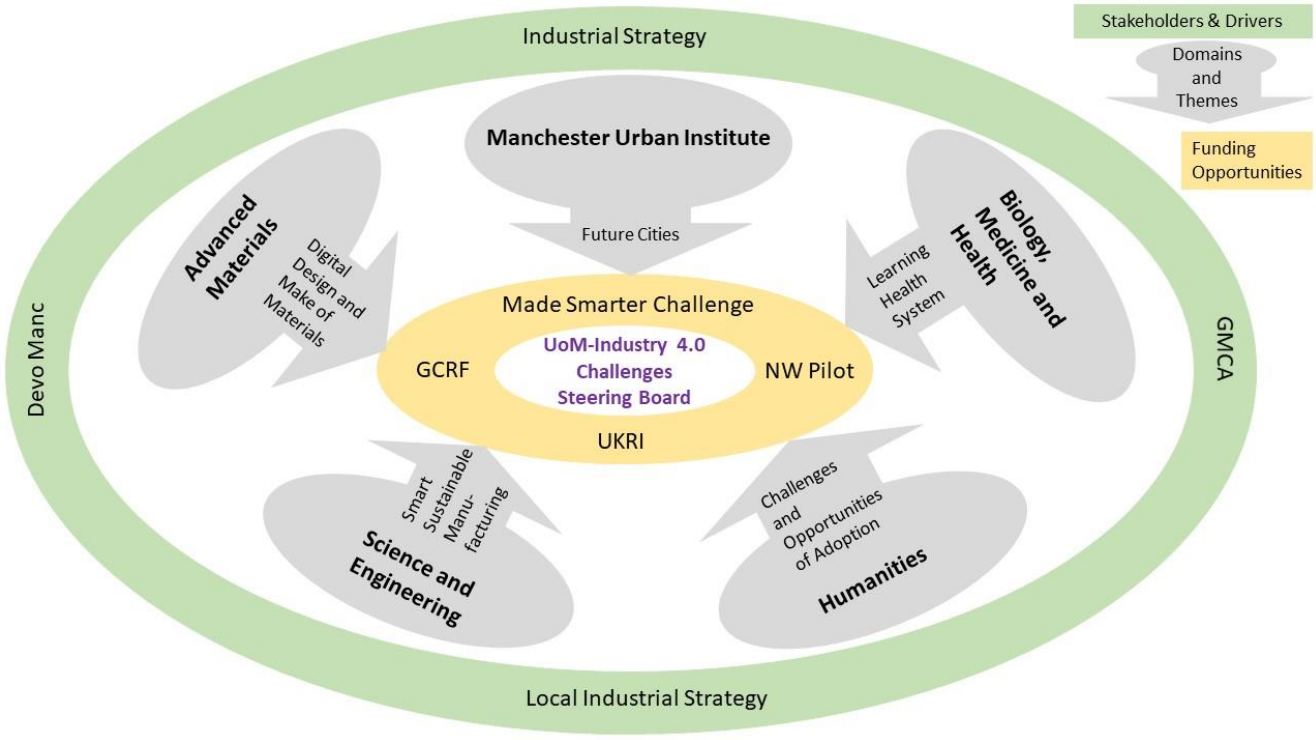
We will champion human-centric Industry 4.0 partnerships:

- **Regionally:** As the biggest university in the UK, and the highest-ranking in the North of England according to the most prestigious world league tables, we will act as both an engine and the connecting medium between the Industry 4.0 stakeholders and drivers in the North West and Greater Manchester.
- **Nationally:** We will propagate our open and entrepreneurial academic ethos to our engagement with the Made Smarter Challenge so that we become an exemplar of a truly inter-disciplinary, human-centric industry-academia partnerships that add value to the supply chain of talent.
- **Internationally:** We will capitalise on our global standing and vast network of international collaborations to build Industry 4.0 capacity where it is needed most.

Framework for Delivery

The Manchester Model aims to create an environment that will position universities as translational hubs that can co-lead on innovation in partnership with industry, supporting lab-to-market solutions that will give the UK a competitive advantage and leadership opportunities in the digital revolution set to transform global manufacture.

Industry 4.0 @ UoM will provide a national exemplar. We call for both national and local Government to promote an environment that will facilitate the delivery of our pilot hub scheme with the view to roll out and establish a national network with strategic HEI partners.



The Made Smarter Challenge will be a flagship opportunity to deliver Manchester solutions for key industrial, economic and societal challenges faced by UK

Domain 1 - Humanities

Overarching Theme: Challenges and Opportunities of Adoption

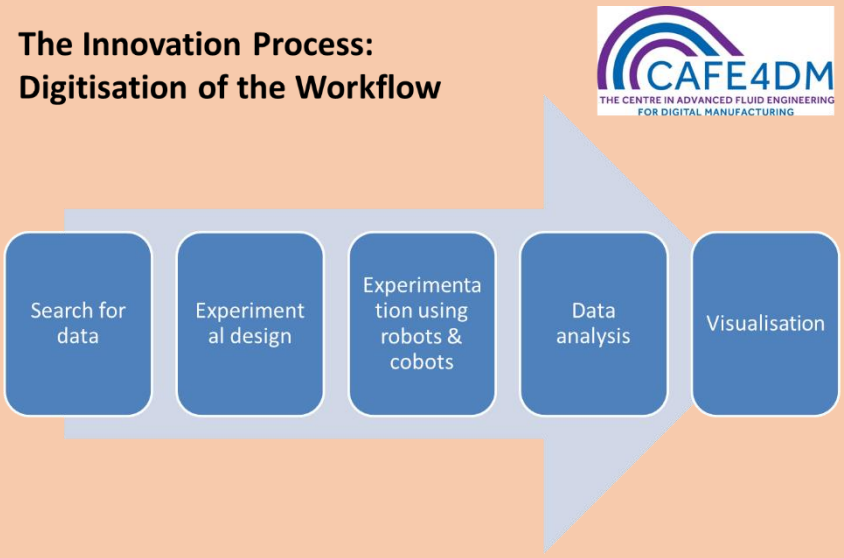
Industry 4.0 is often equated with its enabling technologies such as Internet of Things, Artificial Intelligence and Robotics. In fact these technologies are necessary but not sufficient to implement the vision of Industry 4.0. We also need to learn how the technologies will work alongside people and what the organisational and training prerequisites for successful adoption are. Achieving Industry 4.0 type of demand-driven flexibility means we need to manage the millions of dependencies linking organisations, activities and resources in any manufacturing value chain of realistic size; and to constantly re-align technology, organisation and strategy. These issues are the focal points of research in the Faculty of Humanities, conducted in partnership with various industry partners over the past two decades.

Case Study
Technology adoption and organisational change in corporate R&D

As a part of the 5 year Unilever/EPSRC prosperity partnership project (CAFE4DM), which aims to develop a new digitised modelling approach to enable significant reduction in conventional physical experimentation in the innovation process, Alliance Manchester Business School is leading a work package focusing on the organisational and behavioural issues in the adoption process of digital technology in corporate R&D.

Digitization of the innovation process has been the subject of little research despite the fact that it raises some issues that are very different to those for the digitization of manufacturing. Integrated in the CAFE4DM research framework, this research has a unique advantage to look into the innovation process in Unilever, from idea development, experimental design, to technology scale up and roll out, which enables the research to examine the organisational and behavioural factors that influence the adoption of digitisation in experimentation and innovation and unveil the challenges and opportunities of digitisation in the process industry.

In order to support management on the behavioural change of managers and engineers which is needed to successfully embed Industry 4.0 within the process industry, the researchers undertake a variety of research methodologies, including semi-structured interviews, focus groups, survey, non-participation observations, etc. In particular, the research will promote behavioural change within this new digital environment, identify how leaders can use digital information to make better, quicker decisions, examine how project team members can use data visualisation techniques and data mining to enhance knowledge sharing within teams and manage knowledge transfer between large, distributed teams within companies. The research will finally create a holistic framework on innovation management and behavioural change to facilitate the digitalisation of innovation and Industry 4.0 in the process industry.



Domain 2 – Biology, Medicine and Health

Overarching Theme: Learning Health System

With its strong links to leading healthcare institutions at the heart of Manchester's devolved health system, UoM is uniquely positioned to help optimise the delivery of healthcare at all scales in the system, from an individual health pathway up to the organisation of health economy. We are also tackling the challenge of healthcare's slow adoption of digitisation tech.

Case Study
New digitally-enhanced service for people with heart failure

As part of the government's modern Industrial Strategy which aims to tackle the big societal and industrial challenges of today such as an ageing population, UK Research and Innovation (UKRI) through Health Data Research UK has allocated £338,000 to support the Heart Failure Project. The project was developed by Health Innovation Manchester through an innovative partnership between UoM, Manchester University NHS Foundation Trust, global medical devices company Medtronic and clinical trials specialists North West EHealth.

In one year alone 4,330 admissions to hospitals in Greater Manchester were related to heart failure, with treatment costing more than £17 million. However, by better understanding and supporting the patient to manage their condition this could be much less. Around 1,000 patients with heart failure across Greater Manchester will be monitored by a new digitally-enhanced service that will use data from existing implantable devices to transform care and better meet their needs. The new digital innovation project builds on the existing heart failure and device service at Manchester Heart Centre, at Manchester Royal Infirmary. The clinical team will work closely with Medtronic, the company which provides the devices, to use the data to try and detect signs of deterioration earlier and to transform care for the patient. John Ainsworth, project academic lead and Professor of Health Informatics at UoM, said: "Together with our NHS and industry partners, we will test a new way of working that promises to enable rapid translation of data science research into practice leading to better care and improved outcomes for patients."

Domain 3 – Science and Engineering

Overarching Theme: Smart Sustainable Manufacturing
Sub-themes: Circular Economy, Smart Processes in Food Manufacturing, 3D Printing

This theme involves new products and new ways of producing existing products through the use and coordination of information, automation, computation and cutting edge materials. Enabling technologies include advanced robots, additive manufacturing, advanced laser processes, and IoT. The theme addresses:

- Key economic drivers, such as logistics management and plant maintenance
- Social drivers including personalisation, new small/micro-manufacturing facilities close to the end-consumer, micro-season products, and novel product-service-systems
- Environmental drivers such as zero-emission and zero-defect manufacturing

Case Study
RE3 - Rethinking Resources and Recycling

The University will lead on the UKRI funded 'Rethinking Resources and Recycling' project which is one of eight research projects funded through the Plastics Research Innovation Fund that will explore new and different ways of making, using and recycling plastics. The Manchester-based project has several specific elements looking at plastic production and uses across both consumer-led and industrial sectors. Its primary aim is to reduce the need for plastic by addressing demand and consumer behaviour as well as developing circular economy business models for users to eliminate their plastic waste. It will also evaluate challenges facing new manufacturing processes. The project will also take a practical element with our scientists developing polymers for cleaner degradation and novel soft plastic recycling and micro-plastic removal methods. These include staff from the Schools of: Mechanical Aerospace and Civil Engineering; Materials; Chemical Engineering and Analytical Science; Chemistry and Environment, Education and Development; as well as the Alliance Manchester Business School and several industrial partners. Professor Lin Li, who leads the project, said: "The world is waking up to the global issues posed by plastics pollution. Now is the time to act and Universities, and the wider research community, need to be at the forefront of finding ways to reduce it. This project aims to generate and evaluate new ideas based on coordinated, cross-disciplinary projects and stakeholder engagements."

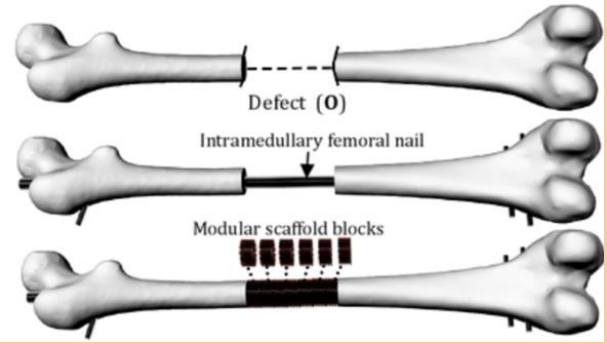
Case Study
PicknPack

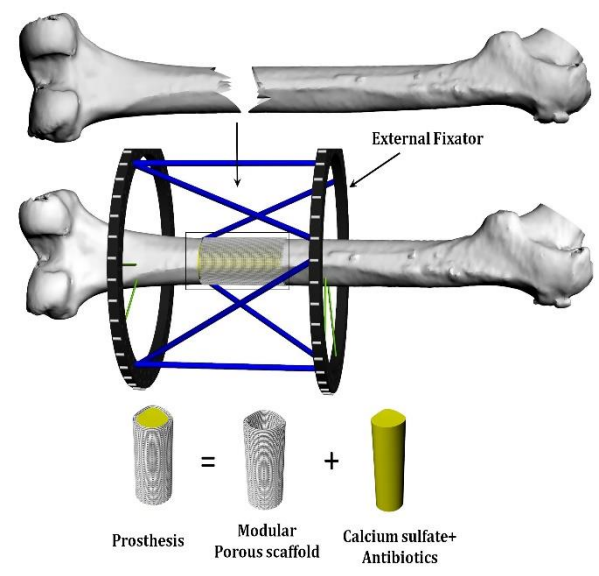
The study is a development of the European Commission Framework Programme 'PicknPack' (PnP) project for automated adaptive packaging of fresh and processed food which was successfully demonstrated in Wageningen in June 2016. A key UoM contribution was the design of an IoT enabled digital architecture employing Machine-to-Machine protocols which allow full inter-operability between the components of an automated line which facilitates flexible manufacturing and the capability of rapid line configuration. Product monitoring using radio-frequency identification (RFID) technology enables total product traceability from factory input bins to market shelf and an object-centric data management system facilitates the rapid interrogation of large production data sets. Line applications are now being explored with a large manufacturer. The IoT concept can of course be extended to encompass the agri-food sector which is rapidly adopting this technology and thus create a complete digital supply chain. This work is complimented at Manchester by the development of a range of non-invasive, low energy sensors to monitor food product quality both during manufacturing and post production to point of sale.

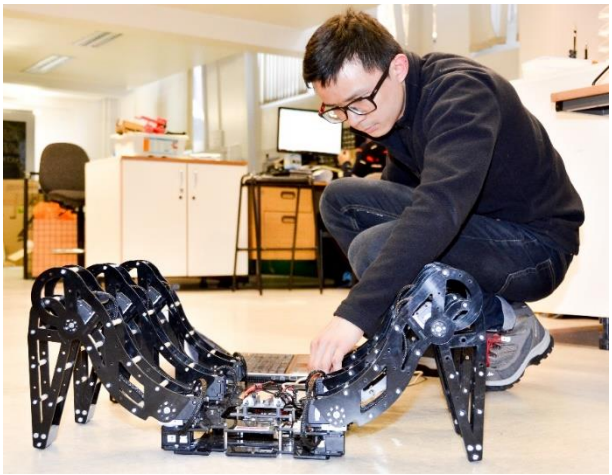
Case Study

Bone Bricks - Cost Effective Modular Osseointegrated Prosthetics or Large Bone Loss Surgical Procedures

The aim of this EPSRC project is to develop and implement a novel low cost osseointegrated modular prosthetic solution to treat large bone loss injuries to enable limb salvage. The immediate application is to treat Syrian refugees who have been displaced to Turkey. The project proposes to build on the current treatment of external fixation but with the addition of an engineered internal prosthetic implant to improve patient outcomes, avoid painful limb lengthening and reduce recovery time. A patient specific prosthetic to fill the bone lost due to injury will be produced using biodegradable and biocompatible modular pieces (bone bricks), from a pallet of shapes and sizes that fit together in a "Lego like" way to form the prosthesis. The assembled prosthesis will create a hollow cage which will be filled with an infection prevention paste containing calcium sulphate and polymeric microbeads encapsulating gentamycin antibiotic. The bone bricks will be manufactured using 3D printing. The infection prevention paste will have low viscosity enabling injection into the implanted prosthetic. The prosthesis and paste will prevent infection, promote bone regeneration creating a mechanically stable bone union. This will enable limb salvage as an alternative to amputation, avoiding painful limb lengthening and improving recovery time/functional patient outcomes.







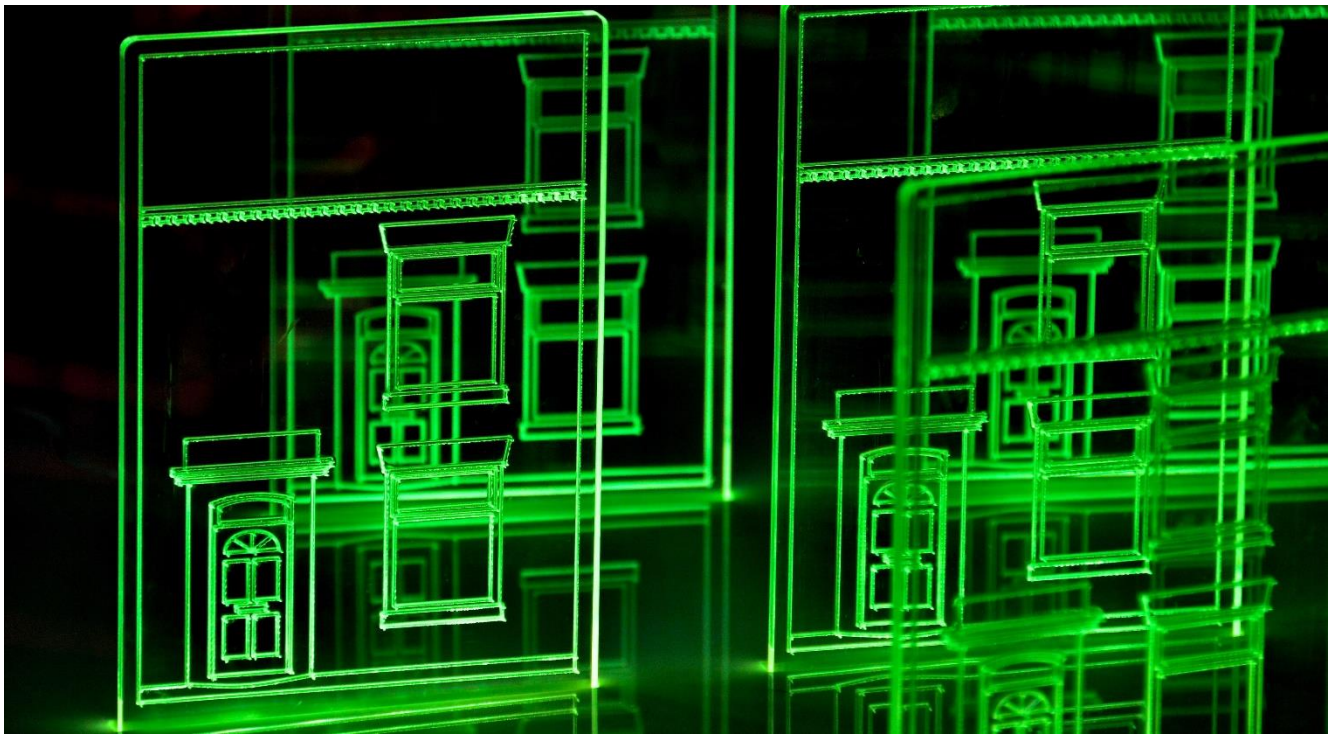
Domain 4 – Manchester Urban Institute

Overarching theme: Future Cities

As the world becomes increasingly urbanised, cities need to become smarter and more sustainable. Policy makers, funding agencies and governments recognise that new approaches are needed to building and living in cities that make them sustainable, resilient and inclusive. Research, technology and data can play a critical role through developing more effective services, engaging citizens in more responsive and creative ways, and enhancing decision-making. The challenge is to develop approaches that work in practice, on the ground, in very different kinds of cities across the world, in ways that are fair and promote social cohesion. Our smart and sustainable city research has helped to attract over fifty million pounds of funding in the past five years, and we work directly with hundreds of partners from across the UK, Europe, Asia and Africa.

Case Study
The Manchester Urban Observatory

The Manchester Urban Observatory builds on expertise developed through >£50m of smart city projects, including CityVerve and Triangulum, to develop an IoT Enabled Urban Living Lab. With unique capabilities in air quality, health and governance, the Manchester Urban Observatory is pioneering a challenge-led approach to apply internet of things technologies to solve pressing urban challenges. The Manchester Urban Observatory will capture >800 existing streams, as well as ~ 400 new streams associated with newly installed sensors. The chosen infrastructure will allow the observatory to study environmental and human health factors from the street level with high temporal resolution to regional trends over months and years. The observatory involves a hierarchy of sensors that straddle static to fully mobile which maintain a minimum level of data quality and allows us to co-locate all sensors across the city region if desired. The ambition is to develop novel interdisciplinary work that brings expertise in health, environment and governance together to generate new insights and solutions to complex urban problems in Manchester but that are characteristic of cities across the world.



Domain 5 – Advanced Materials

Overarching theme: Materials 4.0 - Digital Design and Make of Materials

The challenge in revolutionising materials innovation is huge. Behaviour at the engineering component scale is a consequence of interactions through a hierarchy of structure stretching all the way back to individual atoms. Linking the "recipe" for a new material to its behaviour is highly challenging. Critical to addressing this challenge will be freeing the cycle of new materials development from the traditional empirical paradigm and exploiting digitalization at all stages of design-make-test. This will require the bringing together of expertise from Data Science, Machine Learning and Artificial Intelligence and Mathematics to translate and further develop techniques that have been successfully applied in other domains, such as medical imaging. These digital experts will work with experimental and computational materials scientists to develop an Integrated Computational Materials Engineering (ICME) approach to designing new advanced materials.

Case Study
Graphene Engineering Innovation Centre (GEIC)

GEIC specialises in the rapid development and scale up of graphene and other 2D materials applications. It will focus on the following six application areas to rapidly accelerate the development and commercialisation of new technologies: composites; energy; membranes; inks, formulations and coatings; graphene production; measurements and characterisation.

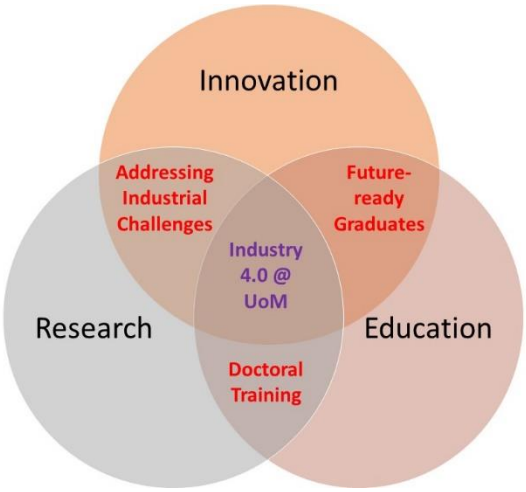
This industry-led innovation centre is designed to work in collaboration with industry partners to create, test and optimise new concepts for delivery to market, along with the processes required for scale up and supply chain integration. With a dedicated team of experienced application managers, application specialists, technicians and its own business engagement team, the GEIC can react as quickly as industry requires.

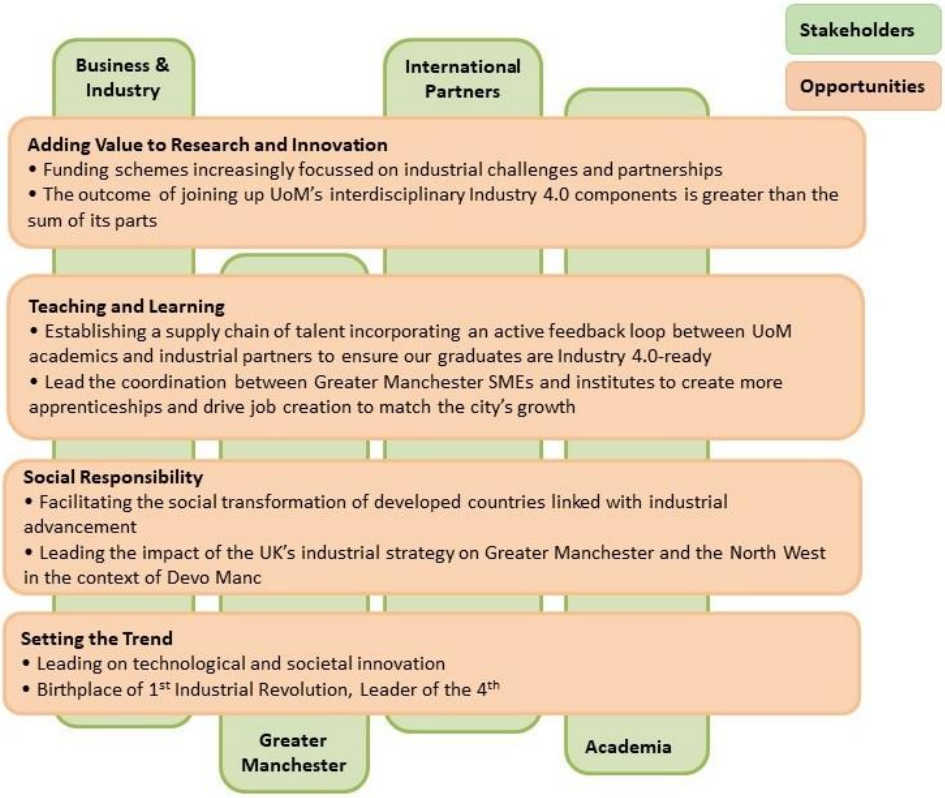
GEIC Funding:

- £15m - Research England
- £30m - Masdar, the Abu Dhabi-based renewable energy company owned by Mubadala
- £5m - Innovate UK
- £5m - European Regional Development Fund (ERDF)
- £5m - Greater Manchester Combined Authority (GMCA)

Summary and Conclusion

With its world-class academic excellence, and the geographic and cultural pull of its home city, UoM is uniquely positioned to be an exemplar of the leadership required from the UK's higher education sector. We have a track record in delivering on areas that are vital for Industry 4.0. This has been made possible by our success at grassroots level, with a critical mass of researchers at the forefront of Industry 4.0 technologies and societal and economic impact.





We are taking steps to cement our place as a world-leading hub for Industry 4.0 solutions in engineering, health and social sciences. We have set out a comprehensive framework spanning national and regional industrial research priorities as well as the teaching and learning approach required to produce future-ready industrialists.

We invite industry leaders to join our vision, by partnering with us in defining these priorities, and collaborating with us in projects large and small, from CPDs to PhDs.

We also call on the Government to encourage an incubating environment for our model as a pilot for the integration of resources that will transform Higher Education Institutions into regional centres of academic and industrial excellence.

Authors

Lead Author

Professor Paulo Bartolo
Chair in Advanced Manufacturing
Industry 4.0 Academic Lead, The University of Manchester

Paulo Bartolo is Head of the Manufacturing Group and Innovative Manufacturing Theme at the School of Mechanical, Aerospace and Civil Engineering, The University of Manchester. He is the University's Industry 4.0 Academic Lead, theme leader of the Industry 4.0 Societal Challenge at Digital Futures and sits on the Management Board of the Centre for Doctoral Training in Regenerative Medicine funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Medical Research Council (MRC). He authored more than 600 publications in journal papers, book chapters and conference proceedings, co-edited 18 books and holds 14 patents, is the Founding Editor of the Virtual and Physical Prototyping Journal (Taylor & Francis) and Editor-in-Chief of the Biomanufacturing Reviews (Springer). He has been engaged in around 90 research projects funded by the EPSRC, Innovate UK, Bill and Melinda Gates Foundation, the Royal Society, the Portuguese Foundation for Science and Technology, the Portuguese Agency for Innovation, the European Commission, and Industry. Paulo is a Fellow of the International Academy of Production Engineering and chairs their Scientific Technical Committee on Electro-Physical and Chemical Processes. He is also member of the MANUFUTURE High Level Group, advisor of the Brazilian Institute of Biofabrication and several National and International Funding Agencies receiving a commendation and public recognition from the Portuguese Government for his outstanding work advising them in the area of research and innovation.

Co-author

Dr Shaden Jaradat
Research Strategy Coordinator
Faculty of Science and Engineering, The University of Manchester

Shaden obtained his BA and MSci in Natural Sciences from the University of Cambridge in 2002 and a PhD in Physics from UoM in 2006. He worked as a Post-Doctoral Research Associate in UoM's School of Physics and Astronomy from 2007 to 2012 before moving to the International Development Division where he managed the University's student recruitment activities in the Middle East and Africa, coordinated the University's policy-setting committee on English language qualifications, and developed relations and partnerships with major sponsors. Shaden was elected in 2017 by representatives of UK HEIs to Co-Chair the UK-Saudi Interest Group, a forum bringing together the British Council, internationalisation colleagues at UK institutions and key stakeholders in Saudi's education sector. In 2018 Shaden joined the Research Strategy Coordination Team in the Faculty of Science and Engineering and has since been tasked with supporting the development of the University's Industry 4.0 Strategy.

Contact us on

Industry4.0@manchester.ac.uk

Domain Leads

Andrew James,
Professor of Innovation Management & Policy
Associate Dean for Business Engagement and External Relations, Humanities
Co-Chief Advisor for the Challenges and Opportunities of Uptake Domain

Andrew is an engaged academic, policy analyst and adviser in the field of science, technology and innovation management and policy. His main research focus is on the defence innovation system and the (changing) organisations, institutions and relationships that underpin technological innovation in the defence and security sectors. He has acted as an advisor and consultant on defence industrial and technological issues to a number of government bodies and industrial companies including the European Commission, European Defence Agency, FOI (the Swedish government's defence research agency), the UK Ministry of Defence, UK Defence Science and Technology Laboratory, the U.S. Department of Defence, Airbus, BAE Systems and Rolls-Royce. He co-founded the Manchester Innovation Forum, a major collaboration between the Manchester Institute of Innovation Research and Greater Manchester Chamber of Commerce which aims to provide a venue for research-led engagement with the business community in the Manchester city region.

Nikolay Mehandjiev,
Professor of Enterprise Information Systems
Co-Chief Advisor for the Challenges and Opportunities of Uptake Domain

Nikolay is Head of the Management Sciences and Marketing Division in Alliance Manchester Business School at UoM. He has initiated and managed projects worth €8m of which € 5.3m to UoM. He delivered modules on Management Information Systems, Simulation, Systems Development, Expert Systems, Business Object Modelling. He also participated in the development and delivery of MBA and BSc Degree Programmes in Information Management.

Lin Li, Professor of Laser Engineering
Associate Dean for Business Engagement and Innovation, Science and Engineering
Co-Chief Advisor for the Smart Sustainable Manufacturing Domain

Professor Li is a Fellow of Royal Academy of Engineering and Director of Laser Processing Research Centre at UoM. He has over 380 publications in peer reviewed journals and 60 patents related to laser processing and photonic science. He was elected to Fellow of International Academy for Production Engineering (CIRP), Fellow of Institute of Engineering and Technology (IET), and Fellow of Laser Institute of America (LIA). He has served on the editorial boards of 13 international journals and President of Laser Institute of America (2016), President of International Academy of Photonics and Laser Engineering (IAPLE, 2013-2015), and President of Association of Industrial Laser Users (AILU). He received Arthur Charles Main Award from the Institute of Mechanical Engineers in 2001 the Sir Frank Whittle Medal from the Royal Academy of Engineering in 2013, and the Wolfson Research Merit Award from the Royal Society.

John Gray, Professor of Robotics and Systems Engineering
Co-Chief Advisor for the Smart Sustainable Manufacturing Domain

John's experience includes five years in the aircraft industry before being appointed as Chair of Control Engineering at Salford University where his work led to the establishment of the UK's National Advanced Robotics Research Centre, in which he served as Research Director for five years before becoming Director of the Centre for Robotics and Automation. He also established the Northern Robotics Network, later expanding nationally. John was appointed as a Professor of Robotics and Systems Engineering at UoM in 2013.

John Ainsworth,
Professor of Health Informatics
Chief Advisor for the Learning Health System Domain
John's career history is not that of a conventional academic; he has a diverse education (BSc Physics, MSc Cognitive Science, PhD Health Informatics) and worked for ten years in industry prior to his academic career. John has worked for Bell Northern Research, Cisco Systems and PA Consulting Group in a wide range of R&D roles in telecoms and data networking. John has been involved in two spin-out companies to develop and commercialise his research - North West eHealth and Affigo CIC.

James Evans, Professor of Geography,
Manchester Urban Institute Smart City Lead
Chief Advisor for the Future Cities Domain
James Evans researches and writes about how cities learn to become smarter and more sustainable. He has more than 70 publications in the field and has worked with a range of organisations to promote urban transformation, including the United Nations, Siemens, Arup and national and local governments. He is committed to innovative and interdisciplinary research and teaching, establishing and directing the University Living Lab and the Manchester Cycling Lab. He is currently the University Lead for Sustainability.

Philip Withers, Regius Professor of Materials
Co-Chief Advisor for the Advanced Materials Domain
Professor Philip Withers obtained his PhD in Metallurgy at Cambridge University and took up a lectureship there, before taking up a Chair in Manchester in 1998. His interests lie in applying advanced techniques to follow the behaviour of engineering and natural materials in real time and in 3D, often as they operate under demanding conditions. In 2005 he was elected to the Royal Academy of Engineering and in 2008 set up the Henry Moseley X-ray Imaging Facility, which is now one of the most extensive suites of 3D X-ray Imaging facilities in the world. Awarded the Royal Society Armourers & Brasiers' Company Prize for pioneering use of neutron and X-ray beams to map stresses and image components in 2010, his work underpins the scientific basis by which we can predict component failure. In 2012, Philip became the inaugural Director of the BP International Centre for Advanced Materials aimed understanding and developing materials across the energy sector. In 2014, UoM was awarded the Queen's Anniversary Prize, recognising the Manchester X-ray Imaging Facility's work. He was elected a Fellow of the Royal Society in 2016. In 2017 he becme the inaugural Regius Professor of Materials and Chief Scientist of the newly founded Henry Royce Insttute for Advanced Materials.

Dr Christopher Race, Royal Society University Research Fellow
Co-Chief Advisor for the Advanced Materials Domain
Chris is a Royal Society University Research Fellow and Senior Research Fellow. He leads the Atomistic Simulation of Materials group within the School of Materials at UoM. He joined the University in 2013 as a Dalton Research Fellow within the Dalton Nuclear Institute. Before that he spent three years in the Department of Computational Materials Design of the Max Planck Institute for Iron Research (Eisenforschung) in Germany, latterly as an Alexander von Humboldt Research Fellow. He obtained his PhD in 2010, in the Department of Physics and Thomas Young Centre, Imperial College London.

Acknowledgements

The authors would like to thank the following for their support of this report:

- Professor Stephen Yeates, Associate Vice-President for Research, UoM
- Professor Chris Taylor, Associate Vice President for Digital Futures, UoM
- Professor Stephen Flint, Associate Vice-President for Internationalisation, UoM
- Professor Wendy Flavell, Vice Dean for Research, Faculty of Science and Engineering, UoM
- MIDAS, Manchester's Inward Investment Agency, particularly Tim Newns, David Hilton, Dan Storer, and John Francis
- Alan Harding, Chief Economic Advisor, Greater Manchester Combined Authority
- Carmel Dickinson, Programme Manager, Digital Futures, UoM
- Liz Caine, Head of Faculty Research and Business Engagement, Faculty of Science and Engineering, UoM
- Patrick Hackett, Sabina Hawthornthwaite, Michael Leverentz, Teresa Chilton and Emilie Brady, Research Strategy Coordination Team at the Faculty of Science and Engineering, UoM
- Tanya Graham and Chris Peters, Policy@Manchester, UoM
- James Tallentire, Marketing And Communications Manager, Faculty of Science and Engineering
- The following UoM Post-Doctoral Research Associates for their artwork contributions: Boyang Huang, Weiguang Wang, Fengyuan Liu and Chao Li.

The authors would also like to thank the UoM Industry 4.0 which includes the following colleagues:

• Prof Andrew James	Professor of Innovation Management & Policy Associate Dean for Business Engagement & External Relations, Faculty of Humanities
• Prof Nikolay Mehandjiev	Professor of Enterprise Information Systems
• Prof Phil Withers	Regius Professor of Materials
• Prof John Ainsworth	Professor of Health Informatics
• Dr Timothy Stallard	Associate Dean for Unit Assessment, Faculty of Science and Engineering
• Prof Lin Li	Professor of Laser Engineering Associate Dean for Business Engagement and Innovation, Faculty of Science and Engineering
• Prof John Gray	Professor of Robotics and Systems Engineering
• Prof James Evans	Professor of Geography, Manchester Urban Institute Smart City Lead
• Dr Christopher Race	Senior Research Fellow, Dalton Nuclear Institute
• Prof Magnus Rattray	Professor of Computational and Systems Biology
• Prof Jian-Bo Yang	Professor of Decision and System Sciences
• Prof Gavin Brown	Professor of Machine Learning, CS
• Carmel Dickinson	Programme Manager, Digital Futures
• Dr Otto Jan Bakker	Lecturer in Mechanical Design
• Prof Allan Matthews	Professor of Surface Engineering and Tribology
• Prof Kody Law	Professor of Applied Mathematics
• Dr Adrian Toland	Head of Business Engagement, Sir Henry Royce Institute

NOTES:

This Strategy Paper is launched at the Industry 4.0 Summit & Expo and Industry 4.0 Academia Summit (Smart Sustainable Manufacturing) – Manchester, April 2019

INDUSTRY 4.0
SUMMIT & EXPO

INDUSTRY 4.0
ACADEMIA
SUMMIT

Contact us on

Industry4.0@manchester.ac.uk