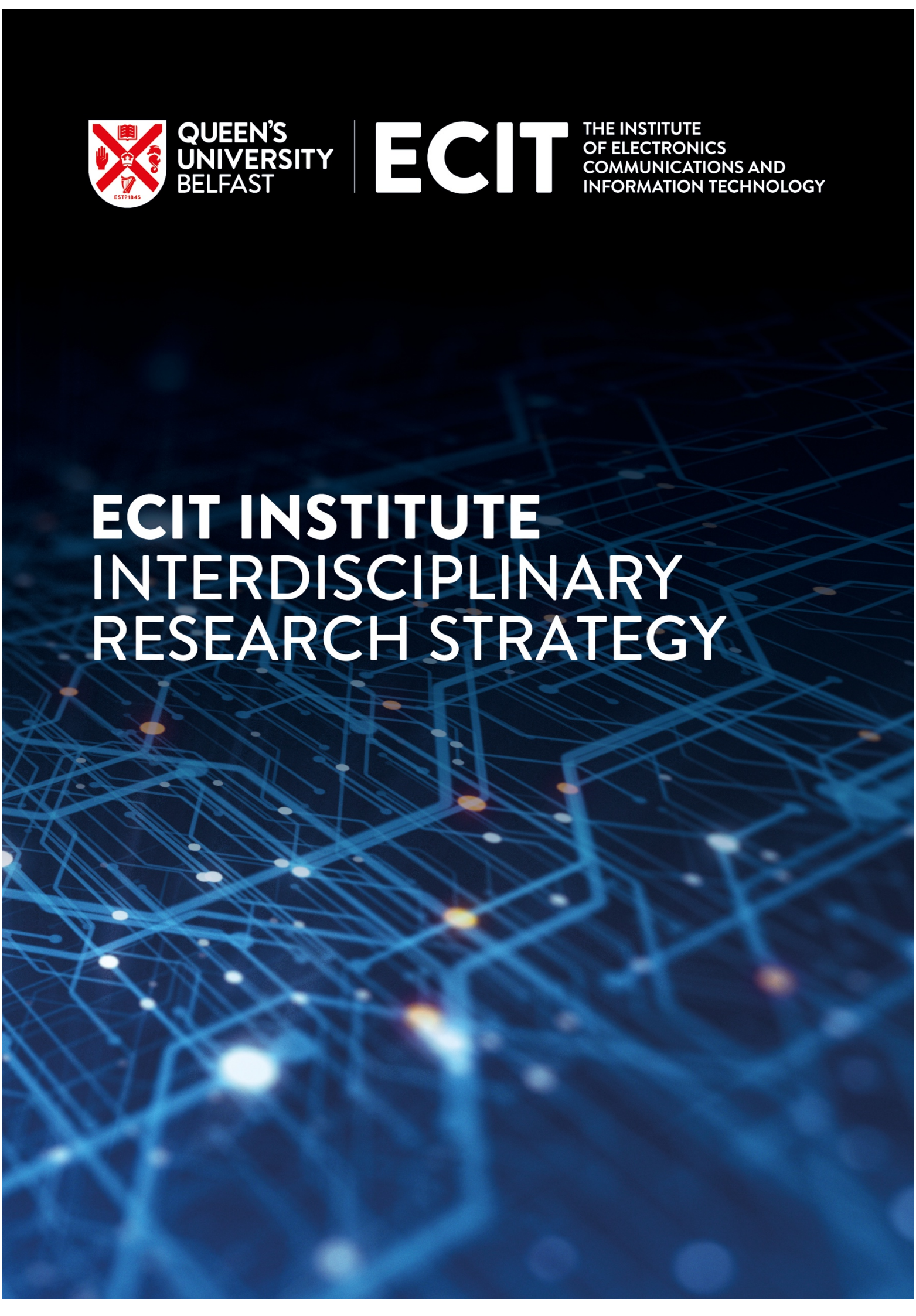
QUEEN'S UNIVERSITY BELFAST

ECIT THE INSTITUTE OF ELECTRONICS COMMUNICATIONS AND INFORMATION TECHNOLOGY

ECIT INSTITUTE INTERDISCIPLINARY RESEARCH STRATEGY



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1.1 Objectives and Scope

This document is primarily aimed at ECIT academics and the senior engineering and commercial team staff who will deliver collaborative projects. However, the document may also be useful to academics from other faculties in setting the scene for how collaborative projects will be initiated and executed in ECIT. It provides an analysis of the present-day research funding landscape and explains the motivations for change towards challenge driven research and innovation programmes. It attempts to identify the attributes and behaviours necessary for ECIT to be successful in this environment. Specifically, it addresses inter/multi-disciplinary research within the Institute and frames the major themes for collaborative engagement between ECIT and QUB faculties. The document was produced in broad consultation with academic groups across QUB. Governance issues around interdisciplinary project selection and execution are discussed.

1.2 Mission Statement

The mission of the ECIT Interdisciplinary Programmes team is to:

1. Improve the Institute's ability to win research funding by teaming with internal QUB research groups and external research centres to create multi- and interdisciplinary teams;
2. Facilitate the creation and preparation of multi- and interdisciplinary project proposals and build mixed consortia consisting of academic and industrial partners, government agencies and civil society stakeholders;
3. Improve the impact of research carried out in ECIT by applying it to a broad set of use cases relating to ECIT's core research strategy of Secure | Connected | Intelligence;
4. Promote cross-faculty collaboration within QUB and catalyse cultural change towards true transdisciplinary research.

1.3 Nomenclature

The document uses the terms *inter-* and *multidisciplinary research* throughout and for clarity they are formally defined below. However, the term *interdisciplinary research* is used by default when precise distinction is unnecessary.

Multidisciplinary Research
Is research conducted between groups from different faculties or thematic specialisms. For example, joint research undertaken by animal behavioural scientists and video analytics specialists would be considered multidisciplinary. Likewise, cancer specialists working with deep learning specialists.

Interdisciplinary Research
Is research conducted broadly within a single functional area such as engineering and mathematical sciences. For example, research between two or more of the ECIT research centres would be classed an interdisciplinary. Research between ECIT and colleagues in the School of EEECS (e.g. EPIC and iAMS staff) would also be considered interdisciplinary as would investigations between ECIT data scientists and colleagues in the School of Mathematics & Physics with similar interests.

Transdisciplinary Research
Cross-disciplinary research activities in a field of investigation can be characterised on a continuum ranging from lower to higher levels of disciplinary integration. Interdisciplinary research is viewed as an additive combination of separate disciplines. Multidisciplinary research provides a deeper

integration of disciplinary approaches; and transdisciplinary research transcends pre-existing disciplinary boundaries. In this sense it opens up the creation of fundamentally new conceptual frameworks, hypotheses, and research strategies that synthesize diverse approaches and ultimately extend beyond them[1].

ECIT is made up of three research centres who are described briefly below. In combination, the three centres investigate interconnected themes of 'Secure Connected Intelligence' in the digital domain.

DSSC
The Centre for Data Science and Scalable Computing is known for research excellence in cognitive signal processing, high-performance and scalable computing, and applied machine learning.

CSIT
The Centre for Secure Information Technologies conducts leading research in security and privacy, hardware and embedded systems security, applied cryptography, cloud and IoT security, network security, malware, industrial control systems security and AI-enabled security.

CWI
The Centre for Wireless Innovation has world leading capability in millimetre-wave and multiple antenna systems and their use in future technologies and applications such as 5G and IoT.

[1] Stokols, D., Hall, K.L., & Vogel, A.L. (2013). Transdisciplinary public health: Core characteristics, definitions, and strategies for success. In Haire-Joshu, D., & McBride, T.D. (Eds.), Transdisciplinary public health: Research, methods, and practice. San Francisco: Jossey-Bass Publishers, 3-30.

2 Research & Innovation Policy Context

Human social and economic advancement occurs in waves or cycles e.g. Kondratieff cycles[2]. ECIT is positioned very much at the nexus of the current wave often referred to as the *Fourth Industrial Revolution* (4IR) and any credible attempt at technology horizon scanning and identification of radical innovation breakthroughs such as the report produced by Warnke et al, 2019[3] will show a strong correlation with ECIT's current research activities. The next wave will be driven by demand factors such as those described in the UN Sustainable Development Goals[4] (SDGs). This demand-led requirement has major implications on research and innovation policy formulation and has led to the mission concept described in Mazzucato 2014[8] and depicted in figure 1.

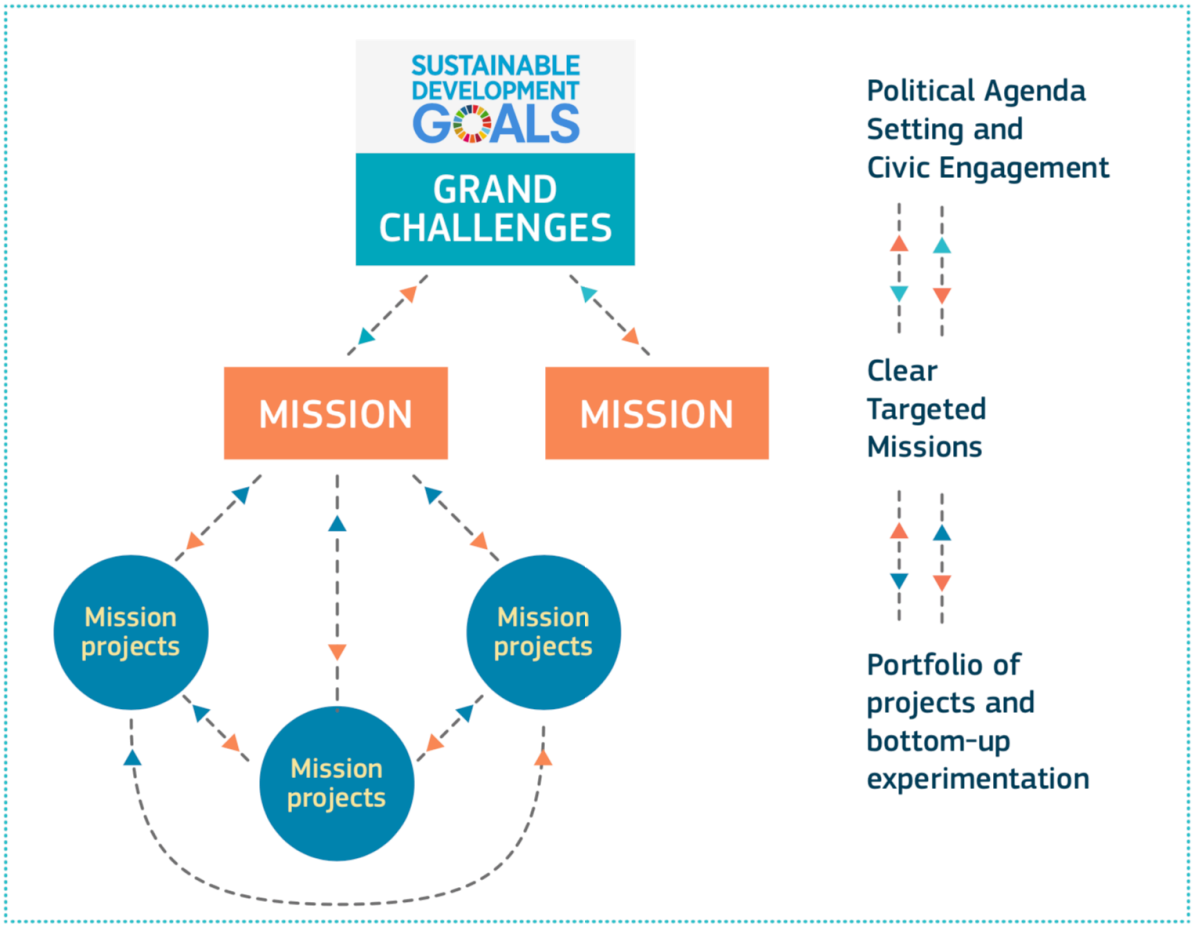

Figure 1: From broad challenges to specific missions (Mazzucato 2018[5])

Classic research and innovation policy (circa 1980) restricted state intervention to funding *public goods* i.e. basic research and fixing market failures where private finance was not available to deal with external factors such as pollution. This reactive policy stance meant that administrations did not attempt to direct markets or *pick winners*; the role of government agencies was to maximise the efficiency of the market and facilitate private enterprise which was always considered to be better placed at managing investments. However, increasing short-termism in private venture capital means that investment has avoided complex but necessary technology that has a gestation period of 5 - 15

[2] https://www.kondratieff.net/kondratieffcycles
[3] 100 Radical Innovation Breakthroughs for the future. European Commission. May 2019. DOI: 10.2777/24537
[4] https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[5] Mission-Oriented Research & Innovation in the European Union: A problem-solving approach to fuel innovation-led growth. European Commission. February 2018. DOI: 10.2777/360325

years. Furthermore, global issues such as the climate crisis and plummeting biodiversity require state managed and coordinated processes of 'socio-technical transitions'[6]. Hence public investment in R&D is increasingly necessary even in advanced economies. The need for a more proactive R&D investment policy was recognised in the UK.

The US Advanced Research Projects Agency (ARPA)[7] established in 1958 performs high-risk research and innovation. Since that time the DARPA (defence) and ARPA-E (energy) programmes have played a stellar role in developing elements of technology such as microprocessor design, DRAM-cache, micro disk drives, lithium-ion batteries, touch screens, SIRI, and the internet protocols that were combined latterly into the modern-day smartphone[8]. This example clearly proves that publicly funded research can be used to not only service existing markets but has the potential to create and shape entirely new markets. That said, the ARPA model is not a silver bullet and critical reports point towards a bias for innovation rather than translational activities that embed technology into the sponsoring organisation[9].

Present day research and innovation policy practiced in the UK not only attempts to increase the rate of R&D spend in companies (the primary aim of Innovate UK) but also attempts to direct investments towards well defined challenges e.g. the Industrial Strategy Challenge Fund (ISCF) circa 2016. Investment policy now covers both rate and *directionality*[8]. Picking winners is common-place and the challenges are chosen on the basis of existing UK-based R&D capacity that can service a large or fast-growing, sustainable global marketplace[10]. This includes societal challenges such as Healthy ageing, Accelerating detection of diseases, and many more industrially focused challenges such as Commercialising quantum technologies, Self-driving cars, Industrial decarbonisation and Manufacturing made smarter. ISCF is part of a £4.7 billion commitment to bolster UK research & innovation over the period 2016 – 2020.

Individual ISCF programmes are led by talented practitioners drawn from industry on fixed duration employment contracts or secondments. These *Challenge Directors* are given a level of autonomy to design and build a portfolio of projects spanning a range of TRLs using funding streams from research councils blended with industry-led projects administered via Innovate UK. The equivalent *Program Manager* role in ARPA has been described as:

> *The DARPA program manager is, in fact, the key. He or she is the technical champion who conceives and owns the program. He is not told what to do, though he does have to have approval from his office director, and from the DARPA Director. Once he starts that program, it is his, and he makes it happen, and he has to make the choices involved in that. So, in essence, they are risk-taking, idea-driven entrepreneurs heading up their own practice. (Van Atta, 2007)*[11]

Selection of projects to be included in (and funded by) a mission is driven primarily by fit and complementarity with the whole project portfolio rather than the pure academic value of an individual project proposal. In some cases (e.g. ARPA programmes) Challenge Directors may have authority and discretion to select relevant projects[7].

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[6] Ellis, G et al. 2020. 'Catalysing and Characterising Transition' https://www.epa.ie/pubs/reports/research/climate/Research_Report_287.pdf

[7] Funding Breakthrough Research: Promises and Challenges of the "ARPA Model". 2019. DOI: 10.1086/699933

[8] A mission-oriented approach to building the entrepreneurial state. Innovate UK. November 2014

[9] US Government Audit Office, November 2015. https://www.gao.gov/products/GAO-16-5

[10] https://www.ukri.org/innovation/industrial-strategy-challenge-fund/

[11] Van Atta, R. H., 2007. Testimony before the Hearing on "Establishing the Advanced Research Projects Agency-Energy (ARPA-E)," Subcommittee on Energy and Environment, Committee on Science and Technology, United States House of Representatives, Washington DC.

Whereas ISCF challenges could be criticised for being narrowly defined or driven by one or a small number of industrial players, the EU Horizon Europe[12] model for mission selection is broader in scope with well-defined selection criteria (Mazzucato 2018[5]):

1. BOLD, INSPIRATIONAL WITH WIDE SOCIETAL RELEVANCE
   Missions should engage the public. They should make clear that through ambitious, bold action at the European level, solutions will be developed that will have an impact on people's daily lives. To do this, missions must outline exciting opportunities for bold innovation — while being connected to debates in society about what the key challenges are, like sustainability, inequality, health, climate change, and increasing the quality of the welfare state.
2. A CLEAR DIRECTION: TARGETED, MEASURABLE AND TIME-BOUND
   Missions need to be very clearly framed. While enabling long-term investments, they need a specific target that can either be formulated in binary ways or quantified. In addition, they will need a clear timeframe within which actions should take place. This needs to be long enough to allow the process to grow, for actors to build relationships and interact, while at the same time being time-limited. Without specific targets and timing, it will not be possible to determine success (or failure), or measure progress towards success.
3. AMBITIOUS BUT REALISTIC RESEARCH & INNOVATION ACTIONS
   Mission objectives should be set in an ambitious manner (taking risks), centred on research and innovation activities across the entire innovation chain, including the feedback effects between basic and applied research. Ambitious objectives will ensure that researchers and innovators are challenged to deliver what would otherwise not be attempted ("additionality" in research). Yet, the objective should be framed to be on the one hand high-risk but also realistically feasible, at least in theory, within the given time period.
4. CROSS-DISCIPLINARY, CROSS-SECTORAL AND CROSS-ACTOR INNOVATION
   Missions should be framed in such a way as to spark activity across, and among, multiple scientific disciplines (including social sciences and humanities), across different industrial sectors (e.g. transport, nutrition, health, services), and different types of actors (public, private, third sector, civil society organisations). Missions need to be chosen to address clear challenges that stimulate the private sector to invest where it would not have otherwise invested ("additionality" in business).

   Problems related to health will not only involve innovation in pharmaceuticals but also in such areas as nutrition, artificial intelligence, mobility and new forms of digitally enhanced public service provision.
5. MULTIPLE, BOTTOM-UP SOLUTIONS
   Missions should not be achievable by a single development path, or by a single technology. They must be open to being addressed by different types of solutions. A mission-based approach is clear on the expected outcome. However, the trajectory to reach the outcome must be based on a bottom-up approach of multiple solutions — of which some will fail or have to be adjusted along the way.

These criteria give a clear indication of the direction of travel and orientation required of ECIT in order to fully capture the value of the planned Global Innovation Institute (GII) and will be adopted moving forward.

Many of the necessary attributes are already in place: ECIT can and does engage in a mix of fundamental research, applied research and industry-led projects; ECIT regularly delivers research outputs in a timely, measurable fashion into targeted programmes; and ECIT contributes to highly ambitious programmes. Attributes which require further improvement include: Public engagement

[12] https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en

and discourse that demonstrates the relevance of our work to the general public; Multidisciplinary collaborative research and co-ordinated, cross-sectoral engagement with industrial partners, civil societies and government stakeholders; and Closer alignment to selected missions and liaison with Challenge Directors in order to maximise opportunities to insert project ideas into established programmes.

Closer alignment to selected missions also involves exerting greater influence on the policy makers and funding bodies most relevant to ECIT. Senior academics are encouraged to engage with UKRI/EPSRC strategic advisory networks and take up seats on Strategic Advisory Teams. Likewise, ECIT early career research staff are encouraged to register as expert assessors (EU Horizon Europe) and panel members (EPSRC) in order to develop a fuller understanding of evaluation criteria and success factors.

2.1 ECIT's Research Funding Posture

Regional specialisation is increasingly becoming a major determinant of success in UKRI funding competitions. Not only in place-based economic development initiatives such as the UKRI Strength in Places Fund[13] but also in increasing expectations of the level of industrial support and co-investment required in bids. For example, a recent DCMS sponsored 5G Create competition[14] expected at least 50% of project costs (up to £5M) to be met by industrial partners. Perhaps as a consequence of this effect, automotive research funding can be traced to UK regions where vehicle manufacturing is strong. Given that Northern Ireland is economically one of the poorest regions in the UK the challenge for ECIT is to carefully target our innovations to those sectors where we can effectively partner with stakeholders to build sectoral strength, increase R&D capacity and demonstrate world class research competency. Making full use of the unique socio-economic attributes and strengths present in Northern Ireland will be key to our future success.

ECIT must become adept at co-creating solutions with end-users and developing a holistic view of complex issues by fully considering the societal aspects, environmental and sustainability aspects, health impacts and potential economic benefits of any given technical approach. Close interworking with QUB colleagues in AHSS, MHLS, EPS, the Mitchell Centre, IGFS, AMIC, iREACH, HAPP, SNBE, and many others will be necessary to achieve success. Co-creation means working with industrial partners and stakeholders to identify their real-world challenges and then assembling teams of multi-disciplinary researchers to creatively engage with the challenge and generate multiple solution sets. Those solutions will be socio-technical in nature. Selection, refinement and implementation of solutions must be done in collaboration with the challenge owner, service users and stakeholders.

Challenge owners will frequently be government agencies such as the Department of Agriculture Environment and Rural Affairs (DAERA) who have responsibility for preserving the ecology and biodiversity of Northern Ireland whilst also optimising the productivity and sustainability of the farming sector. The scale and geography of Northern Ireland lends itself to prototyping new approaches to the circular economy, development of sustainable infrastructure and inciting behaviour change. Another important partner and challenge owner is the Health and Social Care system in Northern Ireland (HSC-NI). HSC-NI is under incredible strain to deal with the complex requirements of service users today and the growing pressure of an ageing population. HSC-NI is a major purchaser of technology but has difficulty in rolling out remote patient monitoring and homecare solutions due to operational challenges relating to the security and privacy of patient information. In other cases, siloed data held in non-interoperable IT systems reduces the utility of otherwise very valuable longitudinal information. Co-creating solutions and frameworks around data-trust using models taken from Trust Law and applying the FAIR principles[15] (Findable, Accessible, Interoperable, Re-useable)

[13] https://www.ukri.org/funding/funding-opportunities/strength-in-places-fund/
[14] https://www.gov.uk/guidance/5g-create
[15] The FAIR Guiding Principles for scientific data management and

would allow ECIT, MHLS and the QUB School of Law to engage with HSC and investigate novel solutions not otherwise available from commercial IT vendors. Funding streams such as SBRI[16] could facilitate such projects.

Partnering with other strong research centres around the world will continue to be a key factor in demonstrating deep research competence in ECIT. ECIT's field weighted citation index (FWCI) for 2019/20 is 2.5 which places the institute amongst the highest ranked Russel Group universities. This level of high-quality academic output makes international centre-to-centre collaborations with ECIT quite attractive. One EPSRC funded international centre-to-centre grant is in place between CSIT/RISE[17] and leading Singapore universities. Similar applications should be encouraged.

ECIT has had considerable success in winning Global Challenge Research Fund (GCRF) funding relating to disaster response and the use of drones to improve situational intelligence and provision of temporary mobile network infrastructure during emergencies. Prof Duong was the first recipient of the Newton Prize Award in 2017[18] which aims to promote the economic development and social welfare of developing countries. On the basis of these high-profile successes, similar applications should be encouraged.

The Brexit Referendum of 2016 and subsequent legislation has largely excluded ECIT from EU funded research programmes. In the 2016/17 academic year, 23% of ECIT research income came from EU sources but that figure has dropped to just 5% in 2019/20. European collaborative research is still possible and cross-border opportunities between Ireland and Northern Ireland are becoming increasingly important:

- **All-island Research Centre Initiatives**
  All-island research centres jointly funded by Science Foundation Ireland (SFI) and the NI Executive are currently under discussion and will focus on areas of common interest such as Food Security, Precision Medicine, Cybersecurity, and Climate Change and Bio-Diversity;
- **EPSRC - SFI Lead Agency Agreement**[19]
  A recent agreement between SFI and EPSRC enables joint applications between research groups in Ireland and Northern Ireland to be submitted as an open call in any research area within the EPSRC remit. SFI will provide a maximum of €500k to Irish research partners;
- **US-Ireland R&D Partnership Programme**[20]
  Set-up as a provision of the 1998 Good Friday Agreement the programme gives access to US-based research calls from the National Science Foundation, the National Institutes for Health and the National Institute for Food and Agriculture. Joint applications must include a partner from each jurisdiction of Ireland, Northern Ireland and the USA.

It is very unlikely that the UK will associate with the EU research programmes commencing in 2021. UK funded replacement schemes are under discussion specifically aimed at providing alternatives to the European Research Council's support for the development of research leaders, the Marie Skłodowska-Curie programme's support for researcher mobility and Horizon Europe's support for industrial technologies and social innovation. Early reports suggest the 2020 *Comprehensive Spending Review* currently underway in Whitehall is favouring sustainability and industrial de-

stewardship" Sci Data 2016 15;3:160018. www.pubmed.ncbi.nlm.nih.gov/26978244/

[16] https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative

[17] Research Institute in Secure Hardware and Embedded Systems. https://www.ukrise.org/

[18] https://www.gov.uk/government/news/uk-vietnam-project-communicating-in-a-disaster-wins-prestigious-newton-prize

[19] https://www.sfi.ie/funding/funding-calls/epsrc-sfi-partnership/

[20] https://www.sfi.ie/funding/funding-calls/us-ireland-rd-partnership/

carbonisation projects - another corollary with the EU's stated policy objective for a European Green Deal[21].

It is difficult to generalise but recent experience of the EPSRC Trustworthy Autonomous Systems Node call where QUB responded with a bid for a £3M multi-disciplinary research node investigating autonomous security, may suggest that sizable EPSRC grants are unlikely to be won by individual institutions. Partnerships with other UK universities should be carefully considered before responding to similar calls of this scale.

ECIT must proactively engage with challenge owners, understand their issues and explore potential solutions sets using multi-disciplinary, creative, co-creation approaches. These activities must be well structured and their outputs captured so that ECIT and partners are in a position to rapidly respond to new funding calls with novel, well evidenced, interdisciplinary proposals.

[21] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

3 Interdisciplinary Project Selection Criteria

The following criteria will act to aid the selection of future interdisciplinary projects in ECIT:

1. ***Clear alignment of project objectives with the annual rolling review research themes listed in Appendix B***
2. ***The selected project provides an opportunity to develop inter/multi-disciplinary research themes that equally benefit ECIT in-house research competencies***
3. ***ECIT has available capacity to support the Proposal Preparation and Project Delivery stages (see section 4)***
4. ***Projects from funding sources where ECIT is well placed to win should be encouraged (e.g. an established relationship with the relevant Challenge Director or insights gained from participation in related Strategic Advisory Teams)***
5. ***Projects that provide opportunities to engage with an ECIT Industrial Advisory Board member company should be encouraged***
6. ***Projects that provide opportunities to engage with recognised international research groups should be encouraged***

ECIT encourages research colleagues from other QUB faculties and disciplines to engage with us and an *ECIT Associate Fellowship* scheme will be launched to ensure that the necessary resources and expertise are on-hand to execute this interdisciplinary research strategy.

4 Principles of Operation

Table 2 summarises the four logical stages in the journey from basic research idea to commercial exploitation and impact. Cross over points between stages are shown in Table 2. ECIT academic staff will have responsibilities in all four phases but the Commercial, Engineering and Interdisciplinary Programmes team-leads will each have prime responsibility for particular stages of the lifecycle and will contribute to others as necessary (depicted in Table 1).

Table 1: Pipeline Responsibility Matrix

	Ideation	Proposal Preparation	Project Delivery	Exploitation
Interdisciplinary	**Prime**	**Prime**	Tertiary	Tertiary
Engineering	Tertiary	Secondary	**Prime**	Tertiary
Commercial	Tertiary	Tertiary	Secondary	**Prime**

An oversight group consisting of the ECIT Interdisciplinary Programmes Director, the Engineering Director and the Head of Business Development will meet on a weekly basis in order to consider new and emerging project opportunities. The oversight group will work with each lead academic (PI) to assess the strategic fit of their new proposal and advise on current resource commitments, utilisation levels and risk exposure in the proposal pipeline. They will work with academic colleagues to identify and mitigate issues as required. To this end, the support teams will maintain a dashboard showing the monetary value of the ECIT proposal pipeline and the aggregate resource commitments made by the Institute over time.

The oversight group will report to the ECIT Senior Management Group on a monthly basis giving details of the current proposal pipeline and highlight any up-coming or open funding calls of interest to the Institute.

Table 2: ECIT Operational Lifecycle - from ideas to commercial exploitation

Ideation	Proposal Preparation	Project Delivery	Exploitation
Interdisciplinary Workshops & Sandpits	Writing Team Formation	Resourcing & Recruitment	Public Comms: • Press Releases • Social Media Campaigns
Funding Call Announcements	Consortium Building	Project Control & Reporting	Graphic Design, Web Resources
Prior Art: • Outline Proposals • Resubmit Old Proposals	Letters of Support	Academic Outputs & Dissemination	Industrial Partners, Stakeholder Liaison
Project Selection Criteria: Go / No-Go →	Proposal Review Process	Technology Demonstrators →	Videos, White Papers, Brochures
Big Ideas	Finance & Approval: Submission →	Archive & document new IP	Trade Shows, Visitors & Demonstrations
Add outline proposals to repository	←Post Evaluation Review	Internal demonstrator projects	IP Licensing, Follow-on projects

4.1 Ideation

Generate ideas for an interdisciplinary project or a research theme. Activities include the following with responsible staff shown in italics:

1. Organising workshops with colleagues from other disciplines – the main output being one or more outline proposals
   (ECIT Interdisciplinary Programmes Director in collaboration with staff from other QUB faculties)
2. Attend sandpit events in relevant topical areas
   (ECIT Research or Engineering Staff)
3. Identify relevant funding calls (and any existing project outlines that fit the scope of that call)
   (ECIT Academics & Interdisciplinary Programmes Director)
4. Work with lead academics to support proposal development to outline stage
   (Interdisciplinary Programmes Director)
5. Assess strategic fit of the outline proposal (using the criteria set out in section 3) and gain approval (from the oversight group) for progression to the Proposal Preparation stage
   (Oversight Group)
6. Particularly strong or novel workshop outputs can also be used to lobby and initiate *Big Ideas* type funding schemes
7. Store workshop outputs as outline proposals in an Interdisciplinary Projects Repository
   (Interdisciplinary Programmes Director)

4.2 Proposal Preparation

Full development of a research project proposal. Activities include the following with responsible staff shown in italics:

1. Form the proposal writing team and set-up appropriate online sharing/collaboration resources
   (Academic PI & Interdisciplinary Programmes Director)
2. Invite relevant Academic and Industrial Partners to join a balanced and sufficient consortium
   (Academic PI & Interdisciplinary Programmes Director)
3. Draft Letters of Support and negotiate support packages with appropriate stakeholders
   (Interdisciplinary Programmes Director & Commercial Team)
4. Formally review the proposal document with relevant expertise from outside the writing team
   (To include Engineering & Commercial Team representatives)
5. Develop the project finances in conjunction with Faculty Finance Dept. Gain approval from ECIT Director before submission
   (Interdisciplinary Programmes Director & Engineering Team)
6. Positive proposal evaluation: Proceed to Project Delivery stage
7. Negative proposal evaluation: Formally review evaluation results with all academic and industrial partners and produce a corrected Outline Proposal for future bids.
   (Academic PI & Interdisciplinary Programmes Director)
8. Store submitted proposals and evaluations in an Interdisciplinary Projects Repository
   (Interdisciplinary Programmes Director)

Note that all ECIT projects must be led by an Academic PI. All proposal writing teams should include an ECR. All projects should engage the Engineering and/or Commercial Teams as appropriate and their costs must be explicitly detailed in project budgets. The ECIT Director will not approve proposals that have bypassed the support teams. In this sense, it is critical that PIs familiarise themselves with the services offered by the Commercial & Engineering teams and the advantages that accrue from their engagement.

4.3 Project Delivery

Perform research and development activities necessary to deliver the project and meet funder expectations. The Academic PI and the Engineering Director will lead this stage. Activities include the following with responsible staff shown in italics:

1. Allocate existing staff resources and recruit new project staff
   (Academic PI & Engineering Director)
2. Perform project control activities and report progress
   (Engineering Director)
3. Perform R&D activities to produce project deliverables and academic outputs
   (Project Staff)
4. Produce technology demonstrators using new academic outputs
   (Engineering Team)
5. Archive and document new IP
   (Engineering Team)

It is strongly recommended that the Engineering Team are used to provide delivery/project management functions on contract research engagements and larger-scale projects that involve mixed industry/academic consortia.

4.4 Exploitation

Find productive routes to deliver impact and commercially exploit research outputs. Activities include the following with responsible staff shown in italics:

1. Project support for public communications i.e. press releases and social media campaigns
   (Academic PI and the Head of Business Development)
2. Project support for graphic design and website construction
   (Academic PI and the Head of Business Development)
3. Outreach and liaison with industrial partners and government stakeholders – highlighting relevant research activity being undertaken in ECIT
   (Head of Business Development)
4. Project support for video making, marketing brochures, white paper creation
   (Academic PI and the Head of Business Development)
5. Attend trade shows and demonstrate new technology
   (Commercial Team)
6. Negotiate IP Licensing deals with interested parties and/or initiate follow-on projects
   (Head of Business Development)

An academic PI checklist is given in Appendix C which provides further detail on activities in the Ideation and Proposal Preparation stages.

5 Interdisciplinary Programmes in ECIT

Appendix B sets out details of four interdisciplinary research themes that are deemed most relevant to ECIT over the next 3 to 5-year period. These themes are expected to build collaborative capacity between ECIT and the QUB faculties and lay the groundwork for the planned Global Innovation Institute (GII). These themes will be reviewed and updated annually to reflect new opportunities and reset direction when necessary.

Appendix B provides the supporting evidence to justify the selection of each theme. It describes the broader landscape of each interdisciplinary programme in terms of the economic importance of the sector to Northern Ireland, the industrial partners who could provide routes to market for innovations in the thematic area, identification of the principal research collaborators and where available concrete use-cases that show a blend of ECIT and third-party research competence. The use-cases are illustrative and not exhaustive. Where possible each ECIT theme refers to a published EU Mission described in Appendix A. In this sense, the boundary of an ECIT interdisciplinary theme is frequently defined by the associated EU mission or a UKRI priority area.

6 Appendix A: EU Research and Innovation Missions

The EU Horizon Europe programme[22] defines five missions which will commence in January 2021 and will run until 2030. Four of these missions, in varying degrees, have direct relevance to ECIT and the GII. The four relevant EU missions and their associated objectives and activities are briefly outlined below because they can be used as a framework to structure and gauge the value of future collaborative engagements with other QUB faculties and third parties. It is unclear whether UK-based research organisations will be eligible to directly participate in Horizon Europe missions but nevertheless as the missions develop and publish their plans they will be a valuable reference point and a comparator to guide activity in the GII.

6.1 Adaptation to climate change including societal transformation

The draft mission outline has been published as – *Accelerating the Transition to a Climate Prepared and Resilient Europe*[23]. Key objectives include: To renovate safe, inclusive, and climate-resilient social infrastructure and neighbourhoods; To save lives and improve wellbeing; To put nature on a path to recovery for the benefit of climate, people, and the planet; To foster innovations towards smart, reliable, and efficient access to water and reduced vulnerability to water-related risks; To shift to diversified and nature-friendly farming, and sustainable consumption.

The latter objective aligns well with ECIT's engagement with the QUB School of Natural and Built Environment on distributed, urban farming. Digital infrastructure designed in ECIT will support the sciences of the environment, provide synergies with the QUB Solutions Centre and align with its focus on climate and biodiversity research. The School of History, Anthropology, Philosophy and Politics (HAPP) contribute to the Belfast Climate Commission and engage with the Place Based Climate Action Network on urban based adaptions. Professor Duong's work on drone-based mobile network infrastructure deployment in disaster response situations sits well with this mission. Cross border co-operation in healthcare or energy networks and grid control would also resonate with this mission.

6.2 Cancer

The draft mission outline has been published as – *Conquering cancer: mission possible*[24]. The goal of the mission is, "By 2030, more than 3 million lives saved, living longer and better". Selected mission actions are listed below i.e. those that reflect potential ECIT contributions:

Understand cancer: Develop understanding of the molecular processes at the cancer cell level and the interactions of the tumour and its host. Enable integration of innovative models and technologies with longitudinal patient data, samples and biomarkers for identification and translation to patients

Polygenic risk scores: Assess the individual cancer risk with refined algorithms based on newly identified polygenic risk scores. The proposed research programme would foster implementation of genomic and informatics infrastructures for (GDPR compliant) data collection and dissemination.

Optimise screening programmes: Big-data analysis and machine learning methods could be integrated in screening and early detection programmes to generate new insights into risks and risk factors.

Advance and implement personalised medicine: As increased precision in cancer management will rely on large datasets for learning as well as advanced methods and standards, this recommendation encourages large-scale collaboration and advanced data analyses in personalised medicine.

Early diagnostic and minimally invasive treatment technologies: Research into modern imaging technology is crucial to speed up the implementation of minimally invasive therapies in clinical practice. With the launch of effective minimally invasive therapies the role of new diagnostic tools

[22] https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en
[23] Accelerating the Transition to a Climate Prepared and Resilient Europe. European Commission. June 2020. DOI: 10.2777/08437
[24] Conquering cancer: mission possible. European Commission. June 2020. DOI: 10.2777/989951

and Artificial Intelligence (AI) is becoming increasingly important to guide treatment procedures and monitor treatment response. Integration of all diagnostic markers, i.e. combining imaging, tissue, genetic, fluid and clinical markers ('integrated diagnostics'), has the potential to increase the accuracy of prediction models of outcome and reduce the use of inefficient diagnostic tools.

Improve the quality of life of cancer patients and survivors: Develop and implement policies and strategies to help cancer survivors assert the 'right to be forgotten', counteract discrimination and strengthen the legal position of individuals with a family history of cancer, cancer patients, survivors and carers.

Collaboration with QUB MHLS research colleagues in cancer, cell biology, medical informatics and public health will enable ECIT to contribute to many related activities aligned to this mission. Furthermore, supporting HSC-NI to secure and manage access to Northern Ireland's integrated health and social care datasets could significantly boost the effectiveness of research in this area and provide valuable longitudinal insights.

6.3 Climate-neutral and smart cities

The draft mission outline has been published as – *100 Climate-Neutral Cities by 2030 - by and for the Citizens*[25] Achieving climate neutrality in cities will require the development and deployment of a vast array of technologies and solutions in all sectors responsible for green-house gas emissions in the city. Smart and digital technologies and the use of data have the potential to facilitate efficiency in use of resources and better decision-making, including by making use of urban systems modelling for mobility, energy consumption in buildings or urban metabolism (resource use and emissions by different economic sectors). This will only be achieved through world-class digital infrastructure and the deployment of the Internet of Things (IoT) and related applications at scale. It will also require open and interoperable datasets, linked and shared across the city ecosystem, that can break down silos and generate actionable insights through big data analytics and the use of Artificial Intelligence (AI).

ECIT's entire research repertoire on the theme of Secure | Connected | Intelligence aligns directly with this mission. Driving efficiency and resilience in power grid infrastructures that incorporates ever larger proportions of renewable energy generation also aligns with this mission. Mission 3 synergises well with the QUB Solutions Centre and its focus on decarbonisation of economies and QUB work on High Value Design, the Factory of the Future, Industry 4.0 and resilient, high efficiency manufacturing all fit within this scope. Systemic changes are required to transport, energy consumption, home heating, urban land-use, local food systems and recycling, all of which will require population-wide behavioural change. None of this can be achieved without preparing civil society for profound impacts to our daily life. Colleagues in politics, law, ethics, social sciences and anthropology all have a role to play in bringing about societal transformation and systemic changes to our local economy.

6.4 Healthy oceans, seas, coastal and inland waters

Not applicable to ECIT.

6.5 Soil health and food

The draft mission outline has been published as - *Caring for Soil is caring for life*[26]. The central objective is to ensure that by 2030 at least 75% of all soils in each EU Member State are healthy, i.e. are able to provide essential ecosystem services. The mission will have wide-reaching impact not only on soil health but also on practices in agriculture, forestry and urban areas as well as the functioning of food and bio-based value chains. Soil health will clearly be the starting point for systemic

[25] 100 Climate-Neutral Cities by 2030 - by and for the Citizens. European Commission. June 2020. DOI: 10.2777/62649

[26] Caring for soil is caring for life. European Commission. May 2020. DOI: 10.2777/918775

transformations across the whole food chain from primary production to food industries and consumer behaviour. Foremost, the mission will result in society rethinking the ways in which it values and cares about soil.

This mission clearly embodies the *One Health* approach that ECIT will pursue with IGFS, MHLS, SNBE and Solutions Centre colleagues in the context of the GII.

> *"One Health is the collaborative effort of multiple professionals, together with related disciplines and institutions — working locally, nationally, and globally — towards optimal health and wellbeing for people, domestic animals, wildlife, plants, and our shared environment."*[27]

The missions are interlinked and to some degree interdependent. For example, improved soil health will naturally allow more nutritious food to be produced containing less contaminants leading to better health outcomes and reduced incidence of cancer in the population. Improved soil and landscape management will also reduce the amount for fertilizer runoff entering waterways and will lead to healthier oceans. Therefore, an integrated land-sea approach to prevent and reduce pollution is crucial, i.e. a societal transformation that reacts to climate change by adopting an increasingly circular economy. 72% of all greenhouse gases are produced in cities and 85% of the population of Europe will live in a city by 2050. Hence cities are where much of the energy efficiency and carbon neutral targets must be achieved via a broadly-based socio-technical transformation that must command the trust and confidence of the population.

[27] One Health Commission. https://www.onehealthcommission.org/

7 Appendix B: ECIT's Interdisciplinary Research Themes 2020 - 2025

7.1 Agri-Tech and Environmental Sustainability

This interdisciplinary theme closely aligns with elements of EU Mission 5: Soil Health & Food (section 6.5) and elements of Mission 1: Adaption to Climate Change Including Societal Transformation (section 6.1). This theme builds on existing collaboration with IGFS, SNBE and AFBI.

7.1.1 Economic Landscape

The Agri-Food sector is crucially important to the economy of Northern Ireland and takes place, critically, in the natural environment where management interventions have direct effects on nature and the ecosystem services that nature provides. NI Agri-Food enterprises employed 40,000 people in 2019, and produced 15% of the UK's dairy products, 15% of UK beef production, 14% of pork and 13% of poultry and eggs – all from 5.5% of the UK's total land mass. The Agri Food sector contributed £1.5B to the economy of Northern Ireland or 3.5% of GVA in 2019[28].

Food and Drinks processing in Northern Ireland was responsible for £5.2B of sales in 2018[29]. 77% of these sales were external to Northern Ireland. Food & Drink represents 35% of the manufacturing sector in Northern Ireland by sales and 27% by employment. Twenty-two companies reported gross turnover of £50M+ in 2018, with the top ten companies representing 50% of the industry, i.e. they were responsible for £2.6B of sales. Beef & mutton products and milk & dairy products are the largest sub-sectors representing almost 50% of the gross turnover. Poultry meat is the most profitable subsector contributing 21% of value added. The foundation of these industries are the managed agricultural ecosystems where food is produced, and the need to maintain the environmental and biological health of these systems is enshrined in a range of national and international legislation and treaties[30]. Policy development which encompasses meaningful responses to the climate crisis, conservation of habitat and biodiversity protection requires a comprehensive and accurate evidence base. Advanced metrology and novel approaches to 'instrumenting the landscape' along with a host of other non-technical interventions spanning legal liability for environmental degradation, redress mechanisms and education, are called for.

[28] NI Agri-Food Sector Key Statistics. DAERA. July 2020. https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Key%20Statistics%202020.pdf

[29] NI Food and Drinks Processing Report 2018. DAERA. https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Northern%20Ireland%20Food%20and%20Drinks%20Processing%20Report%202018.PDF

[30] Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019)
EU Marine Strategy Framework Directive (2008)
EU Water Framework Directive (2000)

7.1.2 Key Industrial Partners

ABP Food Group

Is one of the largest beef processors in Ireland with annual turnover of €3Bn. The company which is based in Co. Louth also operates substantial renewable energy, pet food and protein divisions. ABP Food Group employs over 11,000 people and has 51 manufacturing plants in Ireland, UK, and Europe.

Dale Farm

Dale Farm is one of the leading dairy processors in the UK and Ireland and part of the United Dairy Farmers Group, Northern Ireland's largest dairy co–operative. Dale Farm's product offering includes an extensive selection of dairy goods – ranging from milk, cheese, butter and yogurts to desserts and ice–cream. The company exports to over 45 countries worldwide and reported turnover of £509M in 2018/19.

Devenish Nutrition

Employing over 500 people globally and trading in over 40 countries, Devenish carries out pioneering research and development in health and sustainability throughout the food chain in response to the growing consumer demand for safe, nutritious and sustainably produced food. Headquartered in Belfast, with manufacturing sites in the US, UK, Ireland, Turkey and Uganda, Devenish is a leading provider of feed supplements for ruminants and poultry. Devenish group turnover was £228M in 2018/19.

Dunbia

Tyrone-based Dunbia merged with Waterford-based Dawn Meats in 2017 to produce a beef, lamb and pork meat processing enterprise rivalling ABP in scale. Dunbia has twelve meat processing facilities across the UK and Dawn Meats operate a further 10 in Ireland. They export to 50 countries and reported turnover of approximately €2Bn in 2018/19.

Moy Park

Moy Park is Northern Ireland's largest private sector business and one of Europe's leading poultry producers. With 12 processing and manufacturing units in Northern Ireland, England, France and the Netherlands, the company processes over 280 million birds per year, in addition to producing around 200,000 tons of prepared foods per year. Moy Park reported turnover of £1.6Bn in 2018.

Zoetis Inc.

Formerly the Pfizer Animal Health division, Zoetis Inc. became a fully independent enterprise following an IPO in 2013 which raised $2.2Bn. It is the largest producer of pharmaceuticals for livestock, aquaculture and pets worldwide. The company is in the S&P 500, employs 10,600 staff and reported turnover of $6.3Bn in 2019. Zoetis has stated that expanding its digital and data analytics business is one of its five top priorities in 2020. It sees solutions for "precision livestock farming" as a significant growth driver in the long term. Zoetis have manufacturing sites in Tullamore and Rathdrum in Ireland and offices in Dublin.

Norbrook Laboratories

Norbrook was established in 1969, in Newry, by Edward Haughey (now Lord Ballyedmond) and continues as a family owned, veterinary pharmaceutical company with a portfolio of animal health products which are distributed in more than 100 countries. Their business model is to be the first to market with generic veterinary pharmaceutical products (including antibiotics) with enhancements to the original pioneer products. They reported revenues of £237M in 2019 and employ 1,500 people worldwide.

7.1.3 Collaborative Research Landscape

AFBI – Agri Food and Biosciences Institute

AFBI employs 650 multidisciplinary staff based in seven sites across Northern Ireland. It boasts a model farm in Hillsborough and a 53m marine research vessel docked in Belfast harbour. AFBI provide analytical & diagnostic services, research & development and scientific training & advice in agriculture, food, animal and plant health, marine and freshwater ecosystems and the agri-environment. The Veterinary Sciences Division at Stormont is a UKAS accredited testing laboratory and the Food Standards Agency have designated AFBI as the UK National Reference Laboratory (UK-NRL) for milk and milk products. AFBI was established in 2006 as a non-departmental public body and acts as an independent R&D unit in support of the Department of Agriculture, Environment and Rural Affairs (DAERA). They work closely with staff in the QUB School of Biological Sciences and are actively facilitating live projects.

IGFS – Institute for Global Food Security, QUB

Launched as a QUB Global Research Institute in 2016, IGFS leads research in food security, addressing critical challenges and developing solutions to the complex problem of delivering safe, nutritious, sustainable, authentic food. Multidisciplinary teams anchored in IGFS draw in colleagues internally (from chemistry, pharmacy, School of the Natural Built Environment, AHSS and medicine) and externally (Harvard, Broad Institute, Chinese Academy of Sciences) to transform global food systems with distinctive strengths in sustainable agricultural systems, human nutrition and food integrity. Livestock systems research investigates the health, welfare, productivity and sustainability of high-quality protein production systems in collaboration with AFBI and local industry partners. ECIT has live projects with two IGFS academics: Prof. Niamh O'Connell and Prof. Ilias Kyriazakis. QUB and AFBI are both members of the Centre of Innovation Excellence in Livestock[31] (CIEL) – one of the four UK AgriTech innovation centres established following the publication of the UK Strategy for Agricultural Technologies[32] (2013).

The Solutions Centre (SC), QUB

The SC is a data analysis and synthesis centre and will undertake work focused on providing a range of solutions to address sustainability focused challenges. The centre will deliver research through working groups, integrating Nature based Solutions, Policy and Economic based Solutions, Engineering based Solutions and Technology based Solutions. The Centre's working groups will undertake foresight and horizon scanning activity, address R&D challenges in collaboration with industry, provide the evidence base for the formation of policy with government, and undertake fundamental research addressing disciplinary questions in the sustainability domain. The Centre will bring together researchers from across the three faculties at Queen's, and is partnered with the Belfast City Council, AFBI, and Invest NI. A bid to the NERC is currently in development and will involve ECIT based researchers.

[31] https://www.cielivestock.co.uk/
[32] https://www.gov.uk/government/publications/uk-agricultural-technologies-strategy

HAPP – History, Anthropology, Philosophy & Politics, QUB
HAPP have specific interests in framing questions around societal response to climate crisis and locally based action. Prof. John Barry from HAPP co-chairs the Belfast Climate Commission, which is producing a low carbon pathway to net zero emission by 2050, actively engages communities and businesses locally, links with other cities across the UK (Edinburgh and Leeds), and also explores the financing of a '*just transition*' to a low-carbon, climate resilient economy and society.

School of Natural and Built Environment, QUB
The school investigates the environmental challenges of the Anthropocene era in a holistic and inter-disciplinary manner. Research is structured around three challenge areas:

- *Studying the built environment*
  Environmentally sustainable and resilient urban developments such as Smart Cities that are self-sufficient in energy, food and water and provide a healthy environment for urban dwellers. Re-conceptualisation of urban land use and distributed farming in the city.
- *Studying the changing earth's environment*
  Investigation of marine environments, peatlands, wetlands and contaminated sites from a broad range of perspectives including: Geographical Information Science; Off-shore renewable energy systems; Climatology; Flood alleviation; Carbon capture and storage; Biomonitoring of lakes and waterways.
- *The study of our human worlds*
  A human centric investigation of the factors that drive population geography including heritage, colonialism, ethnic inequalities, ethnic diversity, residential segregation and internal migration. Climate change adaptation of the built environment through the codesign of place-based environmentally beneficial solutions.

NBE is currently working with ECIT on a response to the EPSRC Sustainable Digital Societies call.

7.1.4 Case Studies

Bringing improvements to animal health, welfare and environmental impact of livestock systems through the use of AI
There is an urgent need to reduce, refine and replace the use of antimicrobials and the environmental impacts arising from livestock systems, without compromising animal health, welfare and productivity. This needs to be done in the context of reduced labour input to livestock systems due to cost pressures and the industry trend towards larger operations where it becomes impossible for human operators to physically monitor individual animal performance and health.

Recent advances in sensor engineering, such as electronic identifiers, video cameras and micro dopplers, are now able to capture several features that happen in both indoor and outdoor systems where animals are kept. Behavioural features captured automatically through advanced sensors may be used for the diagnosis and detection of disease and performance assessment. For example, one of the characteristics of several health and welfare challenges is a change in animal behaviour that happens long before a change in their performance or any clinical signs of disease appear. The challenge is to use these features as the basis of an early warning system, preferably operating in real-time. In the first instance we propose to exploit the potential of computer vision, machine learning, deep learning convolutional neural networks (CNN) architectures and cloud computing to develop technology to automatically monitor livestock performance and behaviour. We will explore the possibility of capturing and bringing together through novel analytical techniques, as much information as possible from the sensors and combine it into an effective early warning system of diagnostics and detection. Whilst initially we will focus on detection of generic changes in behaviour,

we will then test whether specific changes can be associated with specific challenges or disorders; the latter will have significant diagnostic value.

A variety of Stakeholders, including companies that focus on the development of sensors (Innovent), pharma industry (Zoetis Inc.) and supermarkets are interested in incorporating the above developments into tools that will automate animal welfare assessment, enable evidence-based decision making in livestock systems and provide early detection of disorders leading to targeted selective action and treatment. For example, early detection of a health and welfare issue may lead to early corrective action, which by definition enhances its chances of success. The above requires close collaboration between animal and veterinary scientists on the one hand, and computer, electrical and electronic engineers on the other to achieve focus and progress.

Carbon Neutral Farming

Decarbonisation of our world includes decarbonisation of the way we produce food. Farming and in particular intensive farming are a large contributor to CO2 emissions. In September 2019, the farming union NFU launched a plan to make British agriculture *carbon neutral* within two decades.

Although cost is an important factor, lack of data to enable us to understand the full carbon cycle is the key factor inhibiting progress, and a priority for the farming industry. "By monitoring crops with satellites, radio-tags on livestock, airborne thermal imaging and ground-level sensors, precision agriculture can help to optimise yields with minimal resource input (such as fertiliser, water and pesticides), which in turn reduces emissions. Furthermore, big-data modelling can predict and monitor pest outbreaks and support future crop planning. Drones with sensors and cameras also provide farmers with an enhanced insight into their land use, aiding decisions such as where best to lay crops and efficiently deploy resources."[33]

In NI, while much relevant data is being collected, it is currently not being combined and translated for action by farmers. A key project co-owned between QUB and AFBI and co-funded by Invest NI and 12 Industry partners, entitled Food Futures, will provide an NI-centric picture of the opportunity. It will be based on a large pilot which will require a wider implementation in NI as a case study for the rest of the world.

Emergency Response: Fly-by Flood Monitoring

Major floods usually result in damage to communication and power supply networks, which are vital services in the early hours of emergency response actions, thus making prompt and evidence-based decision making a formidable task. Accurately evaluating in real-time the situation of an entire region in order to avoid or minimise loss of life, is very challenging. In this project, we propose a real-time flood monitoring system which is assisted by a fleet of amateur unmanned aerial vehicles (UAV) which forms a co-ordinated network that employs fog computing for real-time network optimisation and machine learning. The system is capable of improving prediction accuracy and allowing real-time flood response. The UAV platform is used to collect data from the affected area. Sensors and cameras, deployed in UAV stations, enable early detection, impact assessment and location of survivors. To provide adequate coverage for a disaster area, the limited number of UAVs must be optimised and controlled by a multi-fog computing network. This provides optimised route planning which maximises network lifetime and ensures low network latency. As disaster environments change rapidly, the optimisation solutions must be achieved within micro/milli-seconds. To address this, we

[33] https://www.techuk.org/images/programmes/Technology%20-%20Enabling%20CO2%20reductions%20Final%20Digital%20Version.pdf

use robust ML algorithms, which can adapt to dynamic conditions, facilitate low-complexity decision making, and support self-organising systems with limited human intervention.

Table 3: Summary of Theme 1 Collaborators

Academic Research Groups	
ECIT Institute	Agri-Food & Biosciences Institute
Institute for Global Food Security	SC Solutions Centre
School of Natural & Built Environment	Mitchell Institute
School of History, Anthropology, Philosophy & Politics	School of Law
vHIVE - Veterinary Health Innovation Engine, University of Surrey	CIEL - Centre of Innovation Excellence in Livestock
Industrial Partners	
ABP Food Group	Dale Farm
Dunbia	Devenish Nutrition
Moypark	Zoetis Inc
Norbrook Laboratories	
International Partners	
TBD	

7.2 Health Analytics and Protection of Public Health Data

This interdisciplinary theme closely aligns with EU Mission 2: Cancer (section 6.2) and builds on existing collaboration with the QUB Faculty of Medicine, Health and Life Sciences.

7.2.1 Economic Landscape

Northern Ireland's population of 1.8 million people benefit from an integrated health and social care system, HSC-NI. The HSC facilitates person-centred, joined-up care and lends itself to the adoption and scaling-up of new approaches and interventions[34]. The population size of Northern Ireland is a sweet spot for effective research into the history and determinants of ill health, health inequalities and social factors. Methodology research into the complex systems science that underpins the One Health approach[35] is possible through collaboration between the agencies and research groups present in Northern Ireland. This work is made more urgent by the occurrence of the covid-sars-2 zoonotic virus and the need for more comprehensive approaches to human health that consider food production, animal welfare and ecology.

HSC-NI is unique in the UK in that it maintains a patient record system, stretching back over several decades, which captures all the primary and secondary health and social care events of individual patients. The newly deployed Encompass system[36] in combination with the older NIECR (Electronic Care Record) aim to give a composite picture of the health of the region in one integrated, secure system. Researchers may access these health records via an Honest Broker Service (HBS)[37] operated by HSC NI. HBS provides pseudo-anonymised datasets and extracts to verified research partners. The Cancer Research UK Roadmap[38] emphasises that a clear population perspective is needed for prevention and early detection of all diseases - not just for cancer which accounts for approximately 30% of HSC-NI patients. Digital integrated care records and HBS can provide that population level perspective. Research resources are further enriched with the NI Biobank[39] which collects tumour tissues for a range of malignancies from the gastrointestinal tract, thoracic cavity, breast, lymphoreticular system, head and neck, genitourinary and gynaecological tracts. The Precision Medicine Centre[40] draws together high-throughput genomics, digital pathology and big data analytics in a clinical laboratory environment that provides deep competence in cancer pathology. The other 70% of HSC-NI patients and conditions can be teamed with additional medical research teams such as the Centre for Public Health[41] to provide a macro-level analysis of population health issues and ECIT's competence in AI technologies which could be used to stratify Encompass health records and risk assess asymptomatic and early symptomatic patients across a range of conditions. The use of AI in medicine holds promise that well-structured, data driven algorithms "*may ameliorate human biases*

[34] Precision Medicine in Northern Ireland. Invest NI. Version 05/17
https://www.investni.com/document/25387
[35] https://www.who.int/news-room/q-a-detail/one-health
[36] http://www.hscboard.hscni.net/encompass/
[37] http://www.hscbusiness.hscni.net/services/2454.htm
[38] Early Detection and Diagnosis of Cancer, A Roadmap to the Future. Cancer Research UK, 2020
https://www.cancerresearchuk.org/sites/default/files/early_detection_diagnosis_of_cancer_roadmap.pdf
[39] http://www.nibiobank.org/
[40] https://www.qub.ac.uk/research-centres/PMC/
[41] https://www.qub.ac.uk/research-centres/CentreforPublicHealth/

and attenuate health inequalities"[42]. Predictive algorithms can be used to allocate scare healthcare resources but poor-quality datasets and sampling issues can lead to decisions that are differentially harmful/beneficial across groups. Algorithmic fairness is not a well-defined concept and much ethical and legal opinion is needed to develop frameworks that can evaluate, identify and remedy instances of algorithmic bias. This field of investigation can be further expanded to incorporate social science aspects of collective intelligence via citizen science approaches.

Northern Ireland is a hub for cutting-edge research and innovation in the field of life and health sciences in general and precision health in particular. In close partnership with HSC-NI, ECIT has a role in securing and maintaining privacy in health datasets at both the population level and the individual level when, for example, investigating enabling technology to support privacy preserving analytics over genomic information. Making datasets discoverable, interoperable and accessible to research staff whilst maintaining security and privacy controls; assisting efforts to advance digital pathology through the use of AI techniques; and developing new sensor technology and imaging systems for medical applications; are all open avenues for joint investigation.

7.2.2 Key Industrial Partners

HSC NI

Health and Social Care, Northern Ireland is the agency responsible for delivery of the National Health Service in the region. It is organised into a Health and Social Care Board, five geographic Health and Social Care Trusts (Northern; Southern; South Eastern; Western, Belfast) and an Ambulance Service. There are 350 GP practices in Northern Ireland which act semi-autonomously but do operate common IT systems. The Northern Ireland Audit Office reported in December 2018 that "the health and social care system, as currently configured, is simply unable to cope with the demands being placed on it". None of the NHS targets have been met since 2015[43]. New ways to identify early stage disease and cost-effective treatment pathways, prioritisation of existing waiting lists, and improved cancer treatments are urgently needed.

Almac Group

Allen McClay founded Galen Ltd over fifty years ago and began manufacturing pharmaceuticals in Craigavon. By 1997 the company had exceeded £1Bn turnover and floated on the London Stock Exchange as Galen Holdings PLC. McClay retired from Galen in 2001 but founded Almac in 2002 when Galen agreed to sell back parts of the business to him. Sir Allen McClay died in 2010 but Almac continues to trade strongly reporting revenues of £634M in 2019. It employs 5,600 staff across 18 facilities including Europe, the US and Asia.

The Almac Group are a contract development and manufacturing organisation providing an extensive range of integrated services across the drug development lifecycle to the pharmaceutical and biotech sectors globally. Services range from R&D, biomarker discovery development and commercialisation, API manufacture, analytical services, formulation development, clinical trial supply, IRT (IVRS/IWRS) through to commercial-scale manufacture.

[42] Predictably unequal: understanding and addressing concerns that algorithmic clinical prediction may increase health disparities. Jessica K. Paulus; David M. Kent. Nature Digital Medicine. https://doi.org/10.1038/s41746-020-0304-9

[43] https://www.niauditoffice.gov.uk/sites/niao/files/media-files/205418%20NIAO__General%20Report%20in%20Health%20and%20Socla%20Care_Lwres%20PDF_FINAL.pdf

Randox

Randox was established in 1982 by its Managing Director, Dr Peter Fitzgerald in Crumlin. It now employs 1,500 staff producing in-vitro diagnostic tests and diagnostic reagents and equipment for laboratory medicine which are sold in 145 countries. Randox products and services are used in hospitals, clinical, research and molecular laboratories, food testing, forensic toxicology, life sciences, and veterinary laboratories. They reported revenues of £118M in 2018.

Teva

Teva Pharmaceutical Industries Ltd is the world's leading generic drug maker, with a range of more than 16,000 products that reach an estimated 200 million people every day. Teva UK supplies more medicines to the NHS than any other company. Teva have a research and development facility in Larne and employ 120 people investigating branded and generic developments in implants and intrauterine devices.

Terumo Blood and Cell Technologies

Terumo BCT Inc. is a global leader in blood component and cellular technologies. The Terumo Group is a Japanese healthcare corporation which employs 24,00 people and reported turnover of $5.4 Bn in 2018. Terumo BCT employs 250 people in a manufacturing site in Larne which produces intravenous fluids. The Northern Ireland site is the only FDA approved site within the corporation and currently the only site to manufacture blood bag sets outside Japan.

Philips Life Sciences, Digital and Computational Pathology

PathXL, a QUB spin-out company founded in 2004 developed a range of digital pathology software applications aimed at the research and education segments of pathology and bio-pharma markets. The company had approximately 30 employees, with offices in the UK and USA before it was bought by Philips in 2016. Philips have continued to invest in Belfast and the lab which is now part of the Philips Life Sciences division doubled in size in the first 12 months after takeover. It is now a key asset in the Philips Digital and Computational Pathology business unit.

7.2.3 Collaborative Research Landscape

Precision Medicine Centre of Excellence, QUB

In April 2019 a £10 million funding package from Invest Northern Ireland and the Health and Social Care Research and Development Division enabled QUB to create an internationally accredited laboratory focusing on diagnostics that can be used to predict a cancer patient's response to treatment. This allows potentially costly drugs to be used more effectively.

The long-term vision is to ensure that all cancer patients have access to high-quality, comprehensive and timely molecular characterisation of their tumour to inform therapeutic and clinical management. The centre brings together high-throughput genomics, artificial intelligence and population-wide data analytics in a fully integrated fashion. PMC researchers will work closely with NI biotech companies to develop biomarkers and improve the lives of oncology patients across Northern Ireland and beyond.

Centre for Public Health, QUB

CPH is committed to identifying the epidemiological and genetic risk factors that are important for the health of the individual and of the population and to develop screening and interventions to reduce

the burden of chronic diseases in the future. Thus, advancing the health of the public of Northern Ireland by increasing knowledge and influencing clinical and public health practice and policy.

School of Law, QUB
The School of Law investigates the social and policy space relating to decisions made or influenced by machine intelligence. Data systems can have an impact on the financial security and wellbeing of the patients whose data is shared across the increasingly complex web of health service providers. How do people protect themselves or have agency in terms of how health providers create, store or process patient data in a way that is secure, ethical, consensual and transparent? What are the implications for individuals when their genomic data is leaked? Are there suitable redress mechanisms?

Health Data Research UK (HDR-UK)
Health Data Research UK (HDR-UK) is a £100M national data science institute that was established in 2018 with six sites across the UK including one in QUB which is led by Prof. Mark Lawler, who is also the HDR-UK cancer data science strategy lead. QUB has invested significantly over the last five years to support health informatics and bioinformatics research within the MHLS faculty with further support for data science provided by the ECIT Institute and the School of Mathematics and Physics.

Institute for Research Excellence in Advanced Clinical Healthcare (iREACH)
iREACH is a proposed Innovation Pillar project in the Belfast Region City Deal. It aims to be an integrated clinical research centre of excellence that will develop and deliver innovative clinical trials to drive improved health and social care in Northern Ireland. It will link innovation in clinical trials with investments planned in AI and data science to fully leverage the opportunities that exist at the interface of medical research and digital transformation.

ADR Northern Ireland[44]
The Administrative Data Research Centre Northern Ireland is a consortium of research units from QUB (Centre for Public Health and the School of Management), UU (Bamford Centre for Mental Health) and NISRA the Northern Ireland Statistics & Research Agency. Further support is given by the Health and Social Care Research and Development (HSCR&D) Unit. ADR-NI is funded via an ESRC award of £44M to ADR UK.
The administrative datasets provide a rich view of socio-economic aspects of the population of Northern Ireland. When aggregated with health datasets they enable pioneering research into public health topics such as: The effect of air pollution on health and mortality rates in Northern Ireland[45].

Northern Ireland Longitudinal Study (NILS)[46]
NILS covers 28% of the Northern Ireland population and approximately 50% of Northern Ireland households. The NILS 'core' data are drawn from the Health Card Registration data and then linked to data from Census returns (1981, 1991, 2001 & 2011), Vital Events (births, deaths and marriages), Migration and Property data. The result is over 30 years of longitudinal data which is carefully curated. The QUB contact point is Dr Ian Shuttleworth, School of Natural and Built Environment.

Honest Broker Service[37]
The HSC-NI Business Services Organisation operate an Honest Broker Service (HBS) which mediates access to the health datasets maintained by the five HSC trusts. HBS enables non-identifiable data to be safely shared to maximise the uses and health service benefits which can be gained from health

[44] https://www.adruk.org/about-us/our-partnership/adr-northern-ireland/
[45] https://www.adruk.org/our-work/browse-all-projects/the-effect-of-air-pollution-on-health-and-mortality-204/
[46] https://www.nisra.gov.uk/support/research-support/northern-ireland-longitudinal-study-nils

datasets, including planning, commissioning of services and public health monitoring. The HBS provides access to anonymised, aggregated and in some cases pseudonymised health and social care data to the Department of Health and HSC organisations; and anonymised data for health and social care related research.

7.2.4 Case Studies

Accelerated Diagnosis of Disease and Therapeutic Drug Development

Use of digital tools and multi-modal data sources to empower earlier and more precise diagnosis of human disease and to provide molecular information to guide optimal treatment represent critical opportunities to improve the health and wellbeing of UK citizens. From a life sciences industry sector perspective, molecular diagnostics and targeted therapeutic drug development are key components of a precision medicine strategy that aims to deliver optimal outcomes for patients, while also enhancing innovation and delivering economic and societal benefit. Increasingly this precision medicine domain is enabled by the use of multimodal data to accelerate the discovery, development and delivery of novel companion diagnostics and targeted therapies and specific insights into how data can drive innovation and enhance growth in the life sciences sector. Given Northern Ireland's expertise in the precision medicine domain, an opportunity exists for GII to employ its data analytics skills to empower early stage discovery in both the diagnostic and therapeutic development domains.

Currently, in diseases such as cancer, diagnosis at later stages of the disease continuum means that UK patients have demonstrably poorer outcomes when compared to many of their European and global counterparts. If we could use data intelligence to reduce diagnostic delay in diseases such as lung cancer, colorectal cancer, prostate cancer and breast/ovarian cancer by an average of 50%, we would be able to identify cancer at an earlier stage in nearly 60,000 UK citizens, which would potentially help save around 25,000 lives. Similar opportunities exist for the employment of data from patients with respiratory, inflammatory and eye diseases. Indeed, increased focus on the eye as a potential window to determining health status may represent a distinctive opportunity to develop a data-informed readout of health and wellbeing.

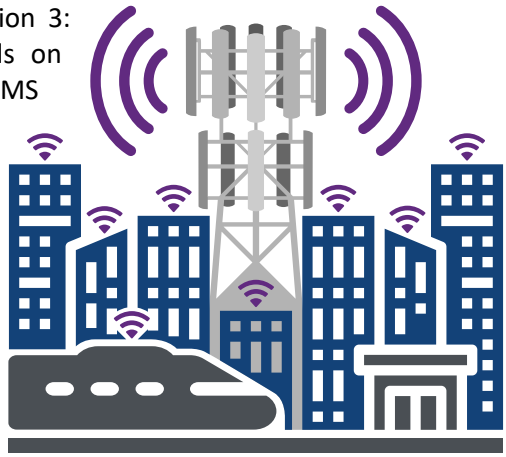
The NI data ecosystem provides particular advantages for a data-enabled approach to enhance detection and diagnosis of disease. Using data to empower earlier and more precise detection of disease also provides crucial information to help inform novel therapeutic target identification, providing a robust conduit to the development of innovative precision medicine diagnostics and treatments, in collaboration with our partners in the pharma, biotech and IT sectors. Focussing on the therapeutic perspective, GII is ideally positioned to apply its expertise in the development and application of machine learning and AI algorithms to the early discovery phase of drug development, providing a significant opportunity to accelerate the delivery of a candidate drug pipeline for subsequent testing in the clinic. Through this data-enabled approach, GII would also support the activities of iREACH, accelerating the development of promising candidates as clinical entities for phase I/first-in-man studies.

Table 4: Summary of Theme 2 Collaborators

Academic Research Groups	
ECIT Institute	Centre for Public Health
Institute for Global Food Security	Precision Medicine Centre
HDR – UK	iREACH
ADR Northern Ireland	NISRA
NILS	SNBE
Mitchell Institute	School of Law
Industrial Partners & Stakeholders	
HSC NI	Almac
Randox	Teva
Terumo Blood and Cell Technologies	Philips Life Sciences, Digital and Computational Pathology
International Partners	
TBD	

7.3 Smart Cities and Secure Connected Intelligent IoT

This interdisciplinary theme closely aligns with EU Mission 3: Carbon-Neutral & Smart Cities (section 6.3) and builds on existing collaboration with two EEECS research centres iAMS and EPIC and the QUB School of Mechanical & Aeronautical Engineering.



7.3.1 Economic Landscape

The services sector accounts for the majority of economic output and employment in Northern Ireland (75% and 80% respectively), a disproportionate number of people work for the public sector (31.8%) and the economy suffers from a large proportion of economically inactive people 26.2% [47]. There is an urgent need to rebalance the NI economy towards new high-value industries and attract private sector investment. The knowledge economy of Northern Ireland is one of the fastest growing in the UK and the region was selected by the Financial Times as one of fDi Intelligence's Top 10 Digital Economies of the Future[48]. Northern Ireland's most innovative companies are found in manufacturing sectoral sub-groups: Manufacture of electrical and optical equipment; Fuels, chemicals, plastic, metals and minerals; and Manufacture of Transport equipment[49]. A cluster of advanced design and manufacturing sites such as Seagate, Sensata, Thales and Short Brothers provides an opportunity to exploit existing research competence in industrial automation & control and high-value design of mechatronic components and composites. Cybersecurity is an important growth sector which promises to improve regional GVA performance which at £22,428 is currently only 78.7% of the UK average[50]. Business expenditure on R&D activities accounts for 1.3% of GVA[51] in Northern Ireland and falls well short of the 2.4% national target. ECIT's mission is to catalyse economic activity and bring wealth and employment opportunities via the exploitation of world class research. Increasing levels of autonomy and cyber-physical systems that directly interact with people raise many questions about safety, security and trustworthiness. These are not solely technological questions. The technical solutions offered in this mission will operate and co-operate, in action with, and in reaction to, their physical and social environments, and must function within complex moral, ethical and legal constructs.

[47] Labour Force Survey Annual Report 2019. NISRA.
https://www.nisra.gov.uk/system/files/statistics/LFSAR-2-Industry-2019.XLSX
[48] This is Northern Ireland. Invest Northern Ireland, May 2020
https://www.investni.com/document/38140
[49] UK Innovation Survey 2017: Northern Ireland Results. NISRA. June 2019
https://www.nisra.gov.uk/sites/nisra.gov.uk/files/publications/UK-Innovation-Survey-2017-Northern-Ireland-Results-Bulletin.pdf
[50] NISRA Economic Output Statistics
https://www.nisra.gov.uk/statistics/economic-output-statistics/gross-value-added
[51] Northern Ireland Research and Development 2018. NISRA, November 2019
https://www.nisra.gov.uk/system/files/statistics/RD2018-Publication.pdf

7.3.2 Key Industrial Partners

Seagate Technologies

The leading computer storage manufacturer is incorporated in Dublin with its operational headquarters in Cupertino, California and has a major production facility in Derry. Seagate was the first company to ship 1 billion hard disk drives (2008) and owns brands such as Maxtor, CDC and Samsung HDD. It reported revenues of $10.3Bn in 2019 and employs over 40,000 staff 1,800 of whom are based in Derry. Seagate is a CSIT industrial advisory board member and maintains a close relationship with the QUB School of Mathematics & Physics.

Sensata Technologies

Sensata Technologies develops sensors, sensor-based solutions, including controllers and software, and other mission-critical products designed for the automotive, heavy vehicle & off-road, industrial and aerospace industries. With more than 21,000 employees and operations in 11 countries the company reported revenues of $3.4Bn in 2019. Sensata's vehicle area network (VAN) product line is being developed in Antrim and provides a scalable platform across commercial on-road trucks and trailers for the OEM and retrofit market. The latter is estimated to be a $1Bn marketplace closely associated with smart distribution and logistics.

Artemis Technologies

Artemis Technologies is an applied technologies spin-off from the successful Artemis Racing America's Cup team. The company was founded in 2017 to commercialise the hydro-foiling technology developed on racing yachts and transfer it to commercial vessels. In 2020, Artemis Technologies won £33M of UKRI funding via the Strength in Places competition. Their project aims to decarbonise commercial passenger ferry services via battery/electric driven e-foiler technology. ECIT, EEECS and the QUB School of Mechanical & Aeronautical Engineering are engaged in the project.

nVIDIA

Titan IC Systems was an ECIT spin-out company (circa 2007) who developed a hardware accelerated content search engine which is programmed by regular expressions. Their work was based on research conducted by Prof Sakir Sezer, Research Director of CSIT's network security group and the co-founder and CTO of Titan IC Systems. The company was acquired by Mellanox in 2020 a US/Israeli networking company and supplier of high-end switches, smart network interface cards and advanced I/O processors to the datacentre market. The Belfast team became a company's centre for advanced network intelligence R&D. Shortly after the announcement nVIDIA bought Mellanox. nVIDIA are a major US-based micro-processor and GPU supplier who are in the process of acquiring ARM Limited in a $40Bn deal.

Cynalytica International

Cynalytica International is a small technology SME incorporated in Belfast but otherwise considered an FDI. They specialize in machine learning and artificial intelligence-based cybersecurity technologies to protect critical energy, transportation, wastewater and industrial control infrastructure. They licensed novel technology developed in the Idaho National Laboratory from the US Dept. of Homeland Security that extends SCADA network monitoring capability into asynchronous control networks.

SONI (System Operator for Northern Ireland)

SONI operate the electricity transmission grid in Northern Ireland and are part of the Single Electricity Market Operator (SEMO) which moderates electricity generation across fossil fuel and renewable sources over the entire island of Ireland. SEMA trades ancillary services and wholesale electricity to electricity distribution network operators such as NIE and ESB and large industrial users in Ireland. This is one of the few examples of a transnational electricity marketplace operating successfully in Europe. The Electric Vehicle recharging network also operates across the island of Ireland and is one of the most advanced in Europe.

Northern Ireland Electricity (NIE)

NIE is the electricity distribution network operator in Northern Ireland. It is responsible for the maintenance and construction of the electricity grid in Northern Ireland although grid design is the responsibility of SONI. NIE distributes approximately 6 GW of power demanded by 860,000 customers at peak. Half of peak demand is frequently met by renewable energy generation, typically wind farms. Maintaining grid stability is a major achievement given the high proportion of renewable energy sources which are unpredictable by nature. This is a unique skill given that mainland GB will not achieve this level of renewables penetration for another five years.

Glen Dimplex

Founded in 1973 in Newry, The Glen Dimplex Group holds significant market positions in the domestic appliance industry worldwide trading under 20+ brand names. The group reported annual revenue of £1.12 Billion in 2019 with 4,800 employees. The GDHV division designs, develops and manufactures professionally installed heating and ventilation systems for residential and commercial buildings including ground source heat pumps. These products provide sophisticated grid communication and control features that implement demand side response techniques.

Short Brothers

Short Brothers is a Belfast-based wholly owned subsidiary of Bombardier Aerospace although the latter announced its intention sell its Belfast operations to Spirit AeroSystems in 2019. The company's products include aircraft components and aerostructures such as carbon fibre-based wings, engine nacelles and aircraft flight control systems for its parent company Bombardier Aerospace, and for Boeing, Rolls-Royce Deutschland, General Electric and Pratt & Whitney. Short Brothers also engage with consortia who bid for UK MoD military aircraft tenders. Short Brothers will manufacture the Artemis Technologies hydro-foiling water taxi and ferry vessels which feature carbon fibre e-foilers.

Thales UK

The Thales UK research and technology division have actively partnered with CSIT since 2009 as members of the industrial advisory board. Their interests are in advanced cryptography, key management systems, hardware security, supply chain security and automotive cybersecurity via the AESIN group. Thales operating divisions also cover space applications and satellites, intelligent transport systems, air traffic control and a range of military/intelligence applications which extend to secure wireless communications.

Leonardo

Leonardo's Innovation & Technology Group have recently signed an NDA agreement with ECIT and are keen to explore collaborative research especially in areas relating to advanced sensors, sensor fusion techniques, and advanced inference systems well beyond machine learning. Leonardo have a range of aerospace, military and enterprise cybersecurity application domains.

BAE Systems

BAE have been a member of the CSIT Industrial Advisory Board since 2009. Their interests range from physical security especially video-analytics, wide-area tracking, pose estimation and high-level semantic analysis of crowd behaviours; to network intelligence and high-grade cryptography. BAE have partnered ECIT on several DASA funded projects. They are the leading supplier of managed cybersecurity services in the UK.

ESA – European Space Agency

ESA fund the development of satellite based advanced sensors, communications antenna and novel metamaterials used to filter and polarise communications channels. ECIT has received considerable funding from ESA over many years and is on their trusted supplier list. Hence, ECIT has access to restricted tender processes.

Rakuten Mobile

Rakuten is referred to as the "Amazon of Japan" and has an extensive e-commerce business offering spanning retail, banking, messaging and more recently mobile network services. Rakuten has over 1 billion users in 29 countries, has 18,00 employees worldwide and reported turnover of £9 Bn in 2019. Rakuten Mobile funded an edge computing research lab in ECIT's Data Science & Scalable Computing (DSSC) centre in 2020 and have a blockchain/fintech software development centre in Belfast.

Analog Devices International

Founded in Massachusetts in 1965, Analog Devices has grown to 16,400 employees worldwide (1,200 in Ireland) and reported $6Bn of revenues in 2019. AD develop electronic sensors used in many industrial sectors such as healthcare, transportation, communications, and industrial automation. AD have a large 491,000 sq ft manufacturing site in Limerick which houses wafer fabrication, engineering and their European R&D offices. ECIT's Centre for Wireless Innovation (CWI) has a longstanding relationship with the ADI European R&D group in the development of novel sensors using mmWave technology.

7.3.3 Collaborative Research Landscape

EPIC – Energy Power and Intelligent Control, QUB

Research within EPIC is focused on problems related to distributed sources of energy and their integration into power networks, control and intelligent systems. EPIC researchers investigate smart grid architectures from the perspective of power engineering, maintenance of power quality, grid stability and controlling reactive power, maintaining synchronisation across federated smart grid architectures and implementing demand side response systems. EPIC works closely with Transmission and Distribution Network Operators who deal with equally large proportions of renewable energy

sources as found in Ireland and their concomitant stability and control challenges. These include Scottish and Southern Electricity and Statnett, Norway.

iAMS – Centre for Intelligent Autonomous Manufacturing Systems, QUB

An interdisciplinary research centre spanning the disciplines of Engineering, Computer Science, Applied Mathematics and Psychology working together to develop innovative technologies and solutions to address the challenges of Industry 4.0 and factories of the future. The disciplines of: Robotics especially parallel kinematic machines; Intelligent control systems especially digital twins; and Data analytics as applied to digital manufacturing, combine to produce intelligent autonomous manufacturing systems that are ultimately self-optimising in terms of manufacturing competitiveness and environmental sustainability. iAMS is hosted in the School of Electrical & Electronic Engineering and Computer Science.

AMIC – Advanced Manufacturing Innovation Centre, QUB

The Belfast Region City Deal includes a £350M Innovation Pillar and AMIC is one of the five flagship projects that make up that Pillar. AMIC will Investigate large-scale, agile digital production systems including high-value design practice and the necessary methods for ensuring the resilience of industrial systems and supply networks particularly for SMEs. Mechanical engineering disciplines of geometric modelling, simulation of functional intent, structural design and performance verification of components alongside bio-inspired design, virtual and augmented reality, and geometric reasoning combine to form rapid design processes that can be verified in the digital domain. These techniques will accelerate the transition from mass production to the efficient manufacturing of low-volume, personalised or bespoke items of arbitrary complexity produced in the locality of the customer. AMIC is led by the School of Mechanical and Aeronautical Engineering.

School of Law

Law has been taught at QUB since 1845 and currently there are more than 800 undergraduate students enrolled in the School, 250 postgraduates, 80+ PhD students and over 50 members of academic staff. There has been an established interest in how law interacts with new technology within the School for some time. In the early 1990s there was a pioneering Masters Programme on Computers and Law, and a group of researchers worked in the area of e-government and e-democracy, advising governments and developing a variety of research projects. There are now research interests across a range of law and technology concerns, including now not only e-government but ranging from IP and Privacy to surveillance, data management and autonomous decision-making, as well as Smart Cities and medical technology. Wider regulation and human rights perspectives inform much of this work. A new Masters in Law and Technology began in 2020 and the Law School has been centrally committed to the Leverhulme Interdisciplinary Network on Cybersecurity (LINCS) since its inception in 2015, and researchers from Law have contributed to a number of research bids in the technology with colleagues across the University.

School of History, Anthropology, Philosophy and Politics

School of History, Anthropology, Philosophy and Politics is an interdisciplinary school comprised four disciplines. Relevant areas of research expertise include environmental politics, sustainable development, energy, security, conflict, technology politics, democracy and participation, borders, migration, terrorism, international relations, ethics, political theory (key concepts and ideas such as freedom, recognition, work). Regional expertise includes the UK, Europe, Ireland, Africa, Latin America, East Asia (China etc.).

7.3.4 Case Studies

Smarter, Healthier Cities

Smart cities have the potential to drive efficient, sustainable and healthier urban environments: a persuasive imperative given that 68% of the world's population are projected to live in urban setting by 2050.[52] Digital technologies that enable intelligent traffic pollution mitigation, promotion of walking and cycling and people taking ownership of their own health and wellbeing are all strong reasons why Smarter, Healthier Cities are a major factor in developing a sustainable environment and productive economy.

Innovations in technology can bring dramatic improvements to living at both a local and global scale. The application of disruptive technologies such as Artificial Intelligence (AI), and the Internet of Things (IoT) in the context of Smarter, Healthier cities will introduce a new paradigm for future generations living in a greener world.

Acquisition of data, its connectivity and understanding of its content are all key to the development of Smarter, Healthier Cities. Hence future living will be centred round a choreographed ecosystem of data driven networks. These networks should be capable of allowing adaptation of existing services and infrastructure to suit the needs of citizens, anywhere, anyplace, anytime.

Cities that are self-aware offer the prospect of healthier and happier places to live. The Internet of Things connected in a secure and intelligent way offers a key driver to realising this. Ubiquitous IoT sensors coupled to complementary technologies such as Wireless, Data Analytics, and AI in a secure, connected, intelligent way can be engineered to yield the core platform on which Smarter Healthier Cities can be developed.

Smart Sensing Technologies in widening AI use-cases

The accuracy of data analytics and the effective use of AI/ML algorithms are highly determined by the quality of data-sets. Furthermore, for many use-cases that require rapid response, the freshness of the live stream of data is paramount.

Sensor technology and the underpinning telemetry/communication technologies critically define the properties and usefulness of collected data. The deployed sensing technology, and the number and the physical proximity of sensors can easily exhaust the bandwidth of available wireless communication channels, hence constraining the effectiveness of collected data. Pre-processing of data at the sensor (or at the edge) that filters relevant data or extracts features of interest can significantly reduce collected data size and significantly improve the delivery and post-processing of these data. Furthermore, the security and integrity of sensor data in motion and also datasets at-rest are important for many safety-critical systems and for preserving privacy.

Novel microwave sensing and imaging technology is currently being developed in ECIT for a range of biological, medical, environmental and security applications. This technology is based on the resonant microwave field enhancement recently discovered by ECIT researchers. This development should lead to new capabilities of microwave sensing technology such as very high sensitivity which can be used for applications such as water quality assessment, soil contamination detection, human cancer detection, and Internet-of-Things sensing. These sensing devices would enable real-time data collection, 5G-compatible wireless connectivity with data processing at the edge or in the cloud and enhanced data security based on physical layer encryption.

GII will therefore work on a challenge-led basis with industry to explore the advancement of Smart Sensing Technologies, targeting the following four topics:

1. New sensor technologies for healthcare and agriculture that enable new ways of collecting data and also improve accuracy and effectiveness of existing sensor technologies. For example,

[52] https://ourworldindata.org/urbanization#what-share-of-people-will-live-in-urban-areas-in-the-future

the use of wireless technology (doppler radio) for non-invasive patient monitoring, such as heart rate, temperature and respiration;

2. Advanced wireless telemetry and communication technologies that enable new ways of deploying sensor technology. For example, ultra-low power wireless sensor technologies for farming and patient monitoring;
3. Edge computing technologies at the sensor or in close proximity of a cluster of sensors for pre-processing of data, filtering of relevant information, or extraction features for direct ML/AI deployment. The focus will be on ultra-low-power computing platforms and new algorithms for filtering, analysing and transforming sensor data;
4. Information and communication security technologies for ensuring the security and integrity of sensor data in motion, secure processing and the secure storage. Compromised sensors or datasets of safety critical systems and medical devices can have disastrous consequences, potentially putting lives at risk. Furthermore, medical and commercially sensitive datasets can be used to extract personal information and must be protected from misuse and unauthorised access.

Queen's Doctoral Training Programme in Secure Connected Intelligent Design and Manufacturing

Artificial Intelligence, robotics, and the Internet of Things are emerging digital technologies with the potential to improve the way we design, manufacture and operate many products and services. Many of today's industrial approaches require transformative change to ensure long-term societal, economic and environmental resilience and sustainability. However, there is a shortage of individuals with expertise and full understanding of the complexity of the industrial challenges, and with the capability to address these through the emerging digital technologies. The Queen's Doctoral Training Programme in Secure Connected Intelligent Design and Manufacturing aims to train graduates that:

1. Are cross-disciplinary, industry-conscious thinkers and leaders who will influence the roadmaps of future advanced manufacturing technologies and their applications;
2. Have a balanced understanding of ICT (security, communications and data analytics) in the context of their application to Advanced Manufacturing and High Value Design;
3. Are equipped with the skills to address challenges that are strongly relevant to industry;
4. Can produce world leading cross-disciplinary scholarly output and impact in areas with high economic and societal value.

The programme is built to align with the delivery of the Belfast Regional City Deal (in particular the Advanced Manufacturing Innovation Centre (AMIC) and The Global Innovation Institute (GII)).

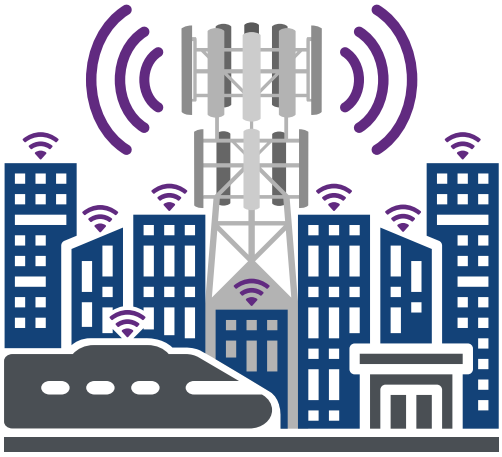
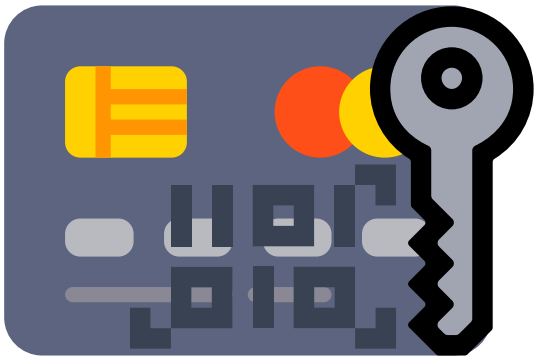


Table 5: Summary of Theme 3 Collaborators

Academic Research Groups	
ECIT Institute	iAMS
School of Natural & Built Environment	AMIC
School of Maths & Physics	EPIC
Mitchell Institute	School of Law
History Anthropology Philosophy & Politics	
Industrial Partners	
Seagate Technologies	Sensata
BAE Systems	Thales UK
Leonardo	Short Brothers
European Space Agency	Scottish & Southern Electricity
SONI	Northern Ireland Electricity
Cynalytica International	Artemis Technologies
Rakuten Mobile	Analog Devices
nVIDIA	ARM
International Partners	
ETRI	SRI
Rochester Institute Technology	SFI LERO
SFI Connected	Tyndall Institute
Stattnet	ESB

7.4 AI-Security for Finance & Insurance

This research theme does not intersect with the published EU Missions given in section 6. However, FinTech and InsurTech are prominent growth sectors in the NI economy and UKRI have acknowledged that research support for service industries (Finance, Accountancy, Law) is weak and should be strengthened. ECIT has an opportunity to further develop the multi-disciplinary research collaborations with AHSS colleagues first established in the LINCS[53] centre for doctoral training programme.



7.4.1 Economic Landscape

The financial services sector is of huge importance to Northern Ireland and recent growth has outstripped London (GVA growing by 6.1 per cent between 2016-17). Throughout the province, around 24,000 people are now employed across a range of specialist subsectors and activities including banking, insurance, FinTech, outsourced solutions, etc. This number increases to 35,000 when finance related professional services are included (e.g. accountancy, consultancy and legal services), contributing £2.4bn to the local economy last year. Digital skills capabilities have allowed NI to develop a reputation as a location for nearshoring of BMO (back middle office) operations as well being a global centre of digital excellence for several large multinationals.[54]

Northern Ireland hosts over 2,000 software engineers and systems architects who develop trading technology platforms for global financial services companies including Citi, Chicago Mercantile Exchange, Cowen Group, Vela Trading Technologies and Fidessa. Another strong cluster of companies is active in governance, risk and compliance (GRC) technology for financial services and other sectors. Consultancy houses PwC and Deloitte have invested heavily in technology teams based in Northern Ireland with PwC Belfast hosting the largest group of blockchain specialists in the consultancy worldwide. Rakuten also have a blockchain lab in Belfast which provides software development services and distributed ledger platforms and solutions to the parent company. FinTech is a vibrant economic sector in Northern Ireland with the prospect of continued rapid growth.

ECIT's contributions will focus on cybersecurity for the financial sector and electronic payments sector, application of advanced AI techniques to provide security in terms of protecting institutions against fraud and external attacks, but also to detect errant behaviour and market manipulation from within the institution. The criminal behaviour of traders, effective compliance approaches to and interpretation of technical law also opens this thematic area to criminology, law and colleagues from AHSS. The use of artificial intelligence to enact law is also within scope. That is, applications of *algorithmic law* and *robot judges* that automatically interpret and enforce regulations without recourse to human expertise.

[53] https://www.qub.ac.uk/Study/funding-scholarships/ahss/LeverhulmeInterdisciplinaryNetworkonCybersecurityandSocietyLINCS.html

[54] Mapping NI's financial services sector. Dept for the Economy https://www.economy-ni.gov.uk/articles/mapping-nis-financial-services-sector

7.4.2 Key Industrial Partners

Allstate

The Allstate Corporation is based in Illinois, employs 45,000 staff worldwide and reported revenues of $44Bn in 2019. It is the largest life/home/car insurance company in North America boasting a customer base of 16 million households. Allstate Northern Ireland has more than 2,300 employees based in three locations - Belfast, Derry and Strabane. It provides technology and software development services to the US parent. Allstate are a proactive member of the CSIT Industrial Advisory Board and have executed large collaborative research projects with ECIT in the area of point of sales detection of fraudulent insurance claims.

First Derivatives

Newry-based First Derivatives PLC was established in 1996 by Brian Conlon in the spare bedroom of his mother's house. The company, which provides software and consulting services to some of the world's largest financial, hi-tech organisations and energy institutions, was floated in 2002. FD's technology stack covers algorithmic trading support, low-latency database systems (Kx) and streaming data analytics software aimed primarily at the Capital Markets industry. FD have 2,400 employees in 15 locations worldwide and reported revenues of £237M in February 2020. FD/Kx are members of the CSIT Industrial Advisory Board and actively encourage research work on streaming graph mining.

Citi Bank

Citi is one of the largest banking groups in the world with approximately 200,000 employees spread across 97 countries. Citigroup reported $19.8Bn of year-on-year revenue in Q2 2020. Citigroup Global Markets Limited and Citigroup NA London Branch are the legal entities present in the UK. London is home of Citi's Europe, the Middle East and Africa (EMEA) region, which consists of operations in 54 countries and does business in another 61. Citigroup employ 2,700 in Belfast's Titanic Quarter. As part of their drive towards robust compliance, risk and control functions, Citi are collaborating with ECIT to investigate automated surveillance of trader behaviours. Citi established their first Innovation Lab dedicated to research and development in the financial services industry in Dublin.

eBay Inc

eBay the San Jose based on-line auction and e-commerce platform is a notable dot-com era success story who previously owned PayPal and Skype. eBay reported revenues of $10.8 Bn in 2019 with 13,300 employees. eBay services 182 million buying customers and operates classified ad platforms such as Autotrader and Gumtree. eBay have over 1,000 Irish employees located in Dublin and Dundalk engaged in multilingual customer support, technology development and operations including their Cyber Crime Security team. Trading, recommendation and analysis systems are heavily dependent on technologies such as AI, computer vision, natural language processing and machine translation. eBay have recently sponsored a PhD student in ECIT to investigate new approaches to software quality assurance in live source code repositories by using deep learning techniques to identify compound security weaknesses.

Liberty Information Technology

Liberty Mutual Insurance Group is a Fortune 100 company based in Massachusetts, USA. They employ 45,000 staff and returned revenue of $43 Bn in 2019. Liberty's technology division has 5,000 staff which includes their Belfast office of 400 software developers, data analysts and DevOps specialists.

CME

Chicago Mercantile Exchange (CME) Group employs 2,500 people in 15 locations around the world. CME is a capital markets specialist who operate four derivatives marketplaces used by investment bankers worldwide to trade futures and options based on interest rates, equity indexes, foreign exchange, energy, agricultural products (including pork bellies) and metals. CME's Belfast Technology and Support Services Centre was established in 2012. The office, which employs more than 300 people, delivers on a broad range of functions including systems/business analysis, software development and quality assurance services.

Fidessa

UK-based Fidessa was founded in 1981 and was listed on the FTSE 250 Index before it was bought by ION Investments Group in 2018 for £1.5 Bn. It reported revenues of £354M for the last financial year before takeover. Fidessa develops trading and workflow automation software solutions to corporates, central banks and financial institutions. Fidessa opened a software development office in Belfast in 2008 and engaged with ECIT via PhD studentships funded through a Capital Markets Collaborative Network (2014-2018).

7.4.3 Collaborative Research Landscape

Senator George J. Mitchell Institute for Global Peace, Security and Justice

Established in 2016, the Mitchell Institute is a flagship for interdisciplinary research in areas of major societal change. It brings together researchers from a wide range of disciplines such as philosophy and ethics, law and criminology, psychology, sociology and international relations to tackle problems relating to justice, peace-making, security, borders and identity. These considerations extend to the cyber domain and raise questions of how can might ensure just and ethical responses to the diverse range of security and privacy risks present in cyberspace? The Mitchell Institute and CSIT established the Leverhulme Interdisciplinary Network on Cybersecurity and Society (LINCS) in 2015 to develop a distinctive cohort of doctoral students working across the boundaries of their respective disciplines.

7.4.4 Case Studies

Security and Assurance for Financial Markets

Preventing and detecting dishonest activities by monitoring financial markets is a significant challenge that has attracted research interest[55,56]. Currently, banks have developed simple rule-based systems that detect specific types of trader abuse. However, many of the alerts generated by such systems

[55] Wang, J., Zhou, S., and Guan, J., "Detecting potential collusive cliques in futures markets based on trading behaviors from real data," Neurocomputing, vol. 92, pp. 44–53, Sep. 2012.

[56] Cao, Y., Li, Y., Coleman, S., Belatreche, A., and McGinnity, T. M., "Detecting Wash Trade in Financial Market Using Digraphs and Dynamic Programming," IEEE Transactions on Neural Networks and Learning Systems, vol. 27, Nov. 2016

correspond to false alarms, resulting in a lack of cost-effectiveness. To address this issue, there is a growing interest in the use of artificial intelligence and machine learning technologies.

Financial institutions are part of the UK's critical national infrastructure and are subject to stringent compliance requirements and regulations. In order to deploy technologies such as AI and machine learning, they require assurance as to how robust they are to cyber-attack. Recently, within the academic AI research community, there has been a growing concern about the security of AI, and how robust it is to adversarial attacks. Current trading abuse practices are a form of adversarial attack on trader surveillance systems, where the trader uses their deep understanding of the trading practices and fraud detection defences to successfully attack the system. There has been a plethora of research into the use of adversarial machine learning but, to date, there has been little focus on attacks against semi- or unsupervised learning systems. The latter form the basis of anomaly detection systems and are crucial to trader surveillance.

Whilst we now know how to train complex machine learning models, we don't yet fully understand how they reach their decisions. One way to build this confidence is to provide insight into the decision-making processes used by the model. A variety of methods have been developed to produce human understandable explanations of model behaviour and how decisions are reached. A model agnostic method has been proposed where the input is modified to measure its effect on the decision output[57]. In addition, model agnostic methods have given insight into how DNNs may be made more robust to adversarial attacks by using techniques from the software testing community[58].

Although promising, purely technical solutions to detect insider trading are not likely to be successful without considering human behavioural contexts and motivations. For example, trader characteristics, such as their socioeconomic status, gender, religiosity and knowledge of the potential legal costs involved have all been found to influence insider trading[59]. How traders mask their errant trading behaviour as compliant and the collusion strategies used to evade detection is an open question for criminology research.

Insurance Technology

The insurance sector is a data rich environment that could be well suited to the data science approaches that have delivered radical and transformative changes in other domains. However, the complex insurance regulatory environment has so far limited the adoption of AI-based technologies. In this context, there is an opportunity for local insurance professionals to develop capacity in novel data science based solutions in order to strategically lead the next generation of innovations in their sector.

Computer Vision

ECIT has deep expertise in the field of computer vision, which is the cluster of technologies that allows a computer to mimic human decision making when looking at a visual input. Application of this technology within the Insurance Industry has not been accomplished at scale. Potential applications include machine learning models that estimate vehicle damage post-accident from large datasets of images taken from historic claims. Computer vision-based solutions would increase the speed of response, provide a better customer experience and improve efficiency of internal operations.

Computer vision capability would also assist in other use cases including processing of aerial imagery of customer rooftops for property insurance pricing and claims processing. Rapid property claims

[57] Ribeiro, M., Singh, S., and Guestrin, C., "Anchors: High-Precision Model-Agnostic Explanations." AAAI Conference on Artificial Intelligence, 2018

[58] X. Xie, L. Ma, H . Wang et al. "DiffChaser: Detecting disagreements for deep neural networks". In International Joint Conference on Artificial Intelligence (IJCAI), 2019

[59] Kallunki, J., Kallunki, J. P., Nilsson, H., and Puhakka, M., "Do an insider's wealth and income matter in the decision to engage in insider trading?". Journal of Financial Economics, 130, 135-165 (2018)

processing and wide area damage assessment in the wake of natural disasters e.g. wildfire catastrophes is another pressing application area. Co-ordinated squadrons of drones can be used to survey whole districts and rapidly determine damage to policy holders' property.

Natural Language Processing (NLP)

Natural Language Processing (NLP) has potential to be deployed in multiple use cases in insurance corporations. Digital platforms are widely used to marshal initial customer contacts e.g. chatbots on websites can go some way to categorise customer queries and pre-process common requests. NLP can be used to summarise and thread together, in real time, the many thousands of customer contact conversations that are processed by insurance chatbot systems. An accurate summary of the conversation is necessary when a call is transferred from a chatbot to a human customer service agent who quickly needs to gain an understanding of the call context. The quality of the context provided at call handover will have a direct effect on customer experience, will affect the length of the call and the productivity of customer service agents.

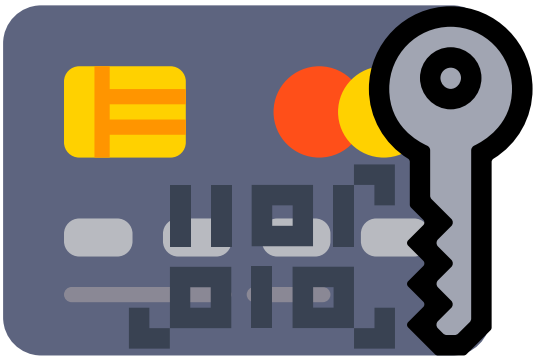


Table 6: Summary of Theme 4 Collaborators

Academic Research Groups	
ECIT Institute	Mitchell Institute
School of Law	
Industrial Partners	
Allstate	Citi Group
First Derivatives	ebay
CME	Liberty Information Technology
Fidessa	
International Partners	
TBD	

8 Appendix C: Academic PI Checklist for Interdisciplinary Projects

The quality gate review process outlined in section 4 is presented below as an activity checklist for academic projects leads which guides them through the first two stages of the project lifecycle. Many of the procedures suggested are aimed at achieving the transparency necessary to enable successful and repeatable collaboration with partners.

Ideation:

1. *Has an ECIT Academic PI or Co-I been assigned to the project?*
   An academic should typically lead a project and in collaborative projects an ECIT academic Co-I is acceptable. ECIT's REF esteem will diminish if non-academic staff take on the PI role. In some limited circumstances a REF returnable ECIT Engineer is acceptable.
2. *Develop a 2-page outline proposal using the template available from the Interdisciplinary Projects Repository*
   Consider project outputs and who would be the first to make use of them?
3. *Are there existing 2-page proposals that may fit within the scope of the call?*
   Use existing prior art from the Interdisciplinary Projects Repository to enhance new proposals and identify potential collaborators.
4. *Does the project clearly align with ECIT Interdisciplinary themes?*
   Review section 7 and references to downstream missions and industrial challenges.
5. *Is there demonstratable evidence of a track record of achievements in related areas?*
   If not, then store the proposal in the Interdisciplinary Projects Repository and initiate small scale activities to build the necessary capacity and publications history.
6. *Submit the 2-page proposal for review by the oversight group made up of the Interdisciplinary Programmes Director, Director of Engineering and Head of Business Development.*
   A review meeting will be held with the Project Lead where the project selection criteria set out in section 3 will be assessed in addition to the requirements listed above. Successful review of the outline proposal enables progression through to the *Proposal Preparation* stage. An outline proposal that does not clearly pass the selection criteria will be escalated to the ECIT CTO for final determination.

Proposal Preparation:

1. *Set-up a project collaboration site on MS Teams and share with all collaborators*
   The funding call document should be added along with the 2-page proposal and any existing presentations/slides. All proposal work items should be stored transparently on this site.
2. *Build a project consortium*
   Use the 2-page proposal as an introduction to the project to attract potential partners. Use the Commercial Team to find potential partners. Invite Industrial Advisory Board member companies whenever possible.
3. *Establish the writing team*
   Schedule the proposal writing activities and incorporate time for consortium wide reviews. When possible, one ECR staff member should be included in the writing team as an opportunity for coaching and mentoring.

4. *Is the project a contract research engagement or a mixed consortium involving commercial partners?*
   If so then engage the Engineering Team to perform project/delivery management functions. Use the Engineering team to build technology demonstrators that integrate with industrial partners' technology and/or opensource libraries that require commercial software/hardware quality levels. Check with ECIT IT that software licence arrangements permit the type of engagement envisaged.
5. *Request letters of support via the ECIT Commercial Team*
   The Commercial Team manage relations with a large set of industrial partners and stakeholders. ECIT will maximise co-operation with our partners by using existing channels of communication - **do not cold call industrial partners**. Initiate this activity in good time.
6. *Develop detailed work package descriptions*
   Use a WP template and add sufficient detail until it becomes clear how much effort is required. It is recommended to plan in detail even if the final proposal will not permit all the information to be presented due to page limit restrictions.
7. *Develop a project budget*
   Allocate budget on the basis of work delivered via Work Packages. Adjust the budget by adding/removing functionality. Ensure appropriate costs for ECIT support staff are included. Engage the EPS Faculty Finance team to check all budget detail. Store all budget information on MS Teams.
8. *Request EPS Faculty Finance to raise an RGAS form*
   Allocate % contribution to all research colleagues and agree these in advance.
9. *Request approval from the ECIT Director*
   The ECIT PI/Co-I should route approvals through their Centre Director who will then forward it to the ECIT Director. Present the following documents: The final proposal document and any attachments; A summary of the personnel commitments being made in ECIT; The final pFact project costing agreed with EPS Faculty Finance.
10. *Submit the proposal via the funder's online portal*
    Only with the ECIT Director's approval.
11. *Store the signed RGAS form on MS Teams.*

Proposal Evaluation:

Successful evaluation enables progression to the *Project Delivery* stage. Unsuccessful evaluations should trigger a consortium wide review as detailed below:

1. *Communicate evaluation results to all consortium partners*
   Distribute all comments from evaluation panels and expert assessors to consortium members and store the information on MS Teams.
2. *Hold a project review meeting with consortium partners*
   Analyse evaluation comments and identify opportunities to strengthen the proposal. Encourage open dialog amongst project partners. Assess likelihood of future success and investigate alternative funding paths. Agree an immediate action plan where possible or suggest a follow-up meeting in three or six months to reassess opportunities.
3. *Update outline proposal with learnings*
   Capture learning points offered by the evaluation by producing a strengthened, updated 2-page proposal and store this on the Interdisciplinary Projects Repository.

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