E3RI

Balanced Solutions for a Better World

Vision & Future Development

June 16, 2020

TCD Board Approved
June 17, 2020
BD/19-20/266

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E3RI – Balanced Solutions for a Better World

As a university we have a responsibility to help solve the most challenging issues of our time. Universities are centres of excellence for research and education. They bring the generations together into a single place and, at their best, they uncover new knowledge, nurture ground-breaking ideas, and encourage a radical approach to problem-solving.

The Engineering, Environment & Emerging Technologies Research Institute (E3RI) is about facing and fully embracing this responsibility. E3RI is about uncovering new knowledge, generating ground-breaking ideas, and taking a radically different approach to dealing with technological development at this critical juncture for the world.

The mega trends that are shaping our world include climate change, large-scale urbanisation, and changing demographics. All of these mega trends have far-reaching implications for our lives and livelihoods and there is an increasing urgency to take action. The climate change challenge, in particular, has grown from what seemed like a distant worry just a couple of decades ago, to one that is now very real and present, as we see greater impact on our world every year. This impact is felt throughout the world, often unevenly, with the most disadvantaged lives being the most impacted.

The rapid digitisation and technological advancement that has taken place in the last decades has played a significant role in exacerbating the challenges we face. E3RI is founded on the fundamental belief that this need not be the case and that it is possible to make technological progress in a way that allows the world to thrive.

Hence, E3RI is essentially about tackling the fundamental issues of a liveable planet, through driving the technological development that is needed for our economy and society in tandem with the social change required.

At the core of the E3 Research Institute is a recognition that technology developed in symbiosis with the natural world can enable us to meet the challenges of our time and create a more sustainable future. This is based in an understanding of the reciprocity that exists between the natural world and our social and financial systems. Figure 1 captures this idea from a natural capital perspective[1].

Natural capital refers to the stock of renewable and non-renewable resources (e.g. plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people. We talk about *ecosystem goods* and *services* being used to drive economic activity. However, we see that the resulting economic activity impacts the natural capital of the world, oftentimes causing it harm and thereby reducing the goods and

[1] We recognise that the term natural capital comes from a particular political framing of the issue

services that it can deliver. This in turn impacts economic activity and society, and so continues a downward spiral.

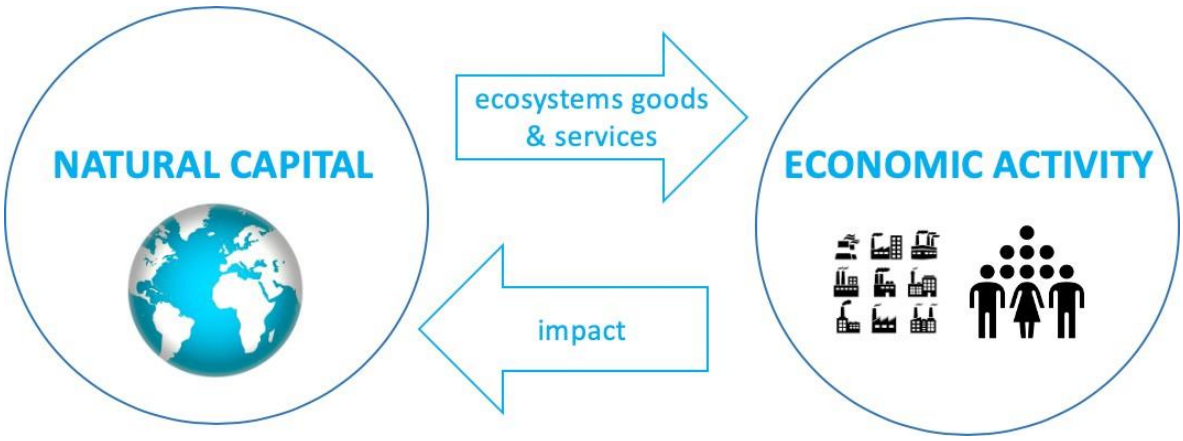


Figure 1: The natural world furnishes us with resources that are needed for economic activity and for society, and that economic activity in turn impacts on the natural world

E3RI is about ensuring that the inter-dependence between the natural world and the economy can and must be a productive one, about ensuring that we can we can evolve technically in harmony with the world, and about creating a circular economy that can work at scale.

We can view all of this through the lens of the industrial revolution. We are now well advanced through the era of the 4th Industrial Revolution. The first three industrial revolutions, it could be argued, had no understanding of their impact on the natural world or on our natural capital. The scientific understanding of this impact, and even the terms we now use to articulate these issues, have only become widely understood in recent decades.

The 4th industrial revolution is characterized by a range of new technologies that fuse the physical, digital and biological worlds, impacting all disciplines, economies and industries, and even challenging ideas about what it means to be human. This inclusion of the biological is significant. Klaus Schwab, in coining the term '4th industrial revolution,' urged that we shape a future that works for all by putting people first, empowering them and constantly reminding ourselves that all of these new technologies are, first and foremost, tools made by people for people. The 4th Industrial Revolution has certainly put 'the biological and the human' in the mix, especially as we increasingly consider the ethical impact of technologies, though there is much further to go.

There is also some understanding of the wider world around us in the 4th industrial revolution. *Industrie 4.0* has a large focus on embedding the built and natural environment with sensors for the purposes of collecting data to aid in the manufacturing process. *Industrie 4.0* also takes a broad view of industry and enterprise; smart cities, smart homes, and smart agriculture and more are included within the term

bringing with them a more rounded view. While some of the measuring and monitoring of resources that takes place is in the service of the natural world, is influenced by sustainability and speaks to a circular economy, the 4th Industrial Revolution, by its very name, suggests a one-sided equation. There is a long way to go to bring the ecological or natural world perspective fully to bear.

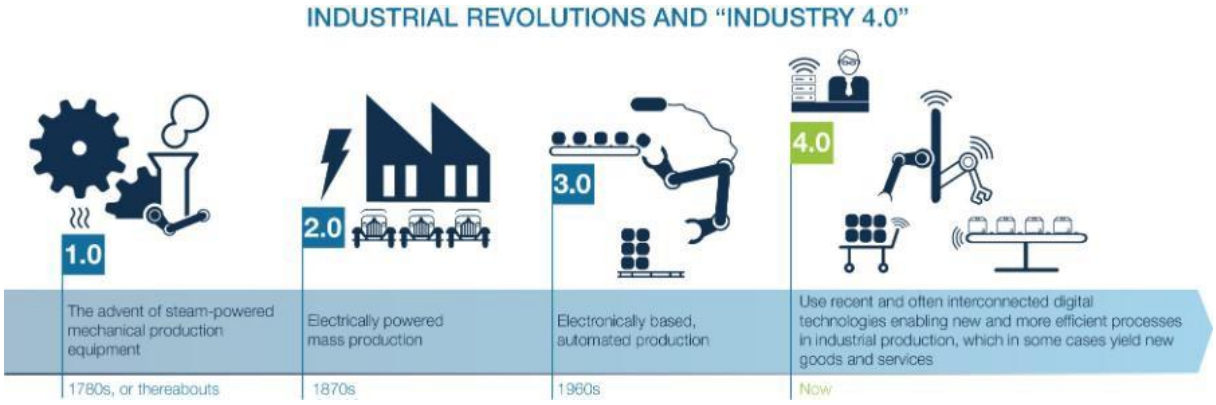


Figure 2: Phases of the Industrial Revolution – currently we are in the 4th Industrial Revolution. The term Industrie 4.0 is also often used to describe this.

It could, therefore, be argued that E3RI is about the next stage in the industrial revolution, an *industrial, technological, ethical and ecological revolution* that will find the balance that we are looking for between the natural world, the digital, the human, a thriving society, and a thriving economy.

In E3RI language we talk about '*balanced solutions for a better world*'. The philosophy behind E3RI is that it is possible to have a vibrant economy while at the same time supporting the natural world and the people, societies and cultures it sustains. We believe the mindset of a balanced solution for a better world is a crucial mindset for making progress on climate action, and other key challenges of our time. We believe that this way of thinking will underpin advances in research and fundamental breakthroughs that can change how the economy works for the better. We believe the next generation of industry will be based on ideas that come from this way of thinking, and if we get it right we can help solve some of the defining challenges of our ages, as well as create sustainable long-term opportunities.

This is made all-the-more challenging as we now also find ourselves in the midst of a global pandemic that is having a profound effect on life, health, well-being, society, culture and the economy. We are facing a world-wide recession that will have further negative consequences, and perhaps facing a future that will work in a very different way from what we had expected. However, that is what research is for: to tackle the most challenging problems of our time and provide solutions to enable new futures we hadn't considered.

Making E3RI a Reality

There are four key elements to making the ambitious and bold plan for E3RI a reality.

1. We will bring researchers in disciplines from across the divide of the natural and the engineered worlds together as part of our Engineering, the Environment and Emerging Technologies Research Institute. E3RI will be one of the first research institutes globally to integrate engineering, technology and the natural sciences at scale to address the challenges of a liveable planet: of balancing the natural world, the digital, the human, a thriving society, and a thriving economy. Added to this, E3RI will draw on a strong track record in nanomaterials, material science and social sciences. The research agenda for E3RI will be one that takes advantage of deep interdisciplinary engagement across this cohort, and will be built on a strong foundation of research excellence. [more details here]

2. We will adopt a *challenge-based* approach to research that will allow us to collectively harness the E3RI expertise for the greater good of society. We will bring our *balanced solution perspective* to bear on the challenges we address. This perspective will drive the kind of industrial, ethical and ecological revolution that we believe is needed to allow the economy to thrive while our natural capital remains replete. [more details here]

3. We will build an exceptional level of partnership with industry and other academic institutions through leveraging the Grand Canal Innovation District (GCID). In the last decade, there has been a growth in a new kind of urban centre known as an Innovation District – where research-oriented institutions, high growth companies and tech and creative start-ups are embedded in an amenity-rich residential and commercial environment. GCID is our district for Ireland, a district designed to maintain Ireland's national global competitiveness and enhance its ability to attract talent and creative companies. E3RI will be a central component of GCID – the jewel in the crown so to speak. Researchers in E3RI can deeply engage with co-located industry and start-ups. E3RI can be a catalysing force for the innovation that will happen in GCID and be the source of the kind of disruptive thinking that can drive change. E3RI can also use the GCID campus to build strategic collaborations with other national and international academic institutions through providing a footprint for those institutions in Dublin. [more details here]

4. We will design and build a research institute that responds to all of these ambitions – one that embodies the best environmental building practices, one that houses the kind of shared cutting-edge infrastructure that is needed for Trinity, Dublin and Ireland, one that supports a highly open and collaborative way of working, and one is inviting to the community. [more details here]

The Value of E3RI for Trinity

A research institute of scale, with ambitions to tackle key problems of our age and with a focus on a liveable planet, is in and of itself a valuable entity. E3RI will allow us to be our best, enable the uncovering of new knowledge, help nurture ground-breaking ideas and encourage a radical approach to problem-solving. The E3RI *raison d'etre* resonates with much that Trinity stands for. In 2019 Trinity was the first Irish university to become a member of the ISCN (International Sustainable Campus Network). Trinity is committed to implementing the nine 'Sustainability Initiatives' developed for the Green Campus Programme which align with the United Nations (UN) Sustainable Development Goals (SDGs). These initiatives are rooted in the values of freedom and independence of thought, respect for individual talents, and commitment to innovative research and active global citizenship.

Beyond this, the creation of E3RI will directly address some crucial needs of the university and in doing so be an investment in the future of the institution.

Located on the Trinity Technology and Enterprise Campus (TTEC) – 10 minutes' walk from the original campus - E3RI will provide much needed research facilities for engineering, environmental and emerging technologies research. Space is at a premium in a city centre campus and we already struggle to accommodate all our needs. More importantly we have a dearth of purpose-built cutting-edge research facilities in the research areas directly involved in E3RI. Dedicated science buildings are now routinely available in the best universities around the world. Trinity is currently significantly lagging behind on this front. We have great talent that would make exceptional use of the kinds of facilities that E3RI will provide, and that will otherwise be held back from reaching their full research potential.

Moreover, E3RI will give us the opportunity to grow and take advantage of emerging opportunities, opportunities that are not possible within the confines of current space and facilities. These include opportunities to attract new talent to Trinity. World class facilities in E3RI will be a major attractor for this new talent. We will also have the opportunity to dream bigger about the kind of research projects for which we seek funding. E3RI will allow us to expand – our imaginations and our physical footprint -

and apply to host projects we otherwise could simply not accommodate were we successful.

E3RI also matters for teaching and learning. Our research informs our teaching and no where will it be more evident than in the E3 Learning Foundry (E3LF). The research carried out in E3RI will directly inform the teaching in E3LF. New staff attracted to Trinity through E3RI will also teach in E3LF and contribute to developing curricula that draw from the very latest advancements. A number of new professorial positions have been approved in the Schools of Engineering, Natural Sciences and Computer Science and Statistics:

Engineering	**Natural Sciences**	**Computer Science & Statistics**
Sensor/Actuator Technology	Climate Science	Data Science
Embedded/Control/Optimisation	Geoinformatics - GIS	Resources
Engineering Education	Surface process	Wellbeing
Neural Engineering	Paleo Climatology	Software Systems
Multi-Physics/Modelling	Transitions Management (sustainability)	AI
Process control/chemical engineering	Nature Based Solutions (from the inorganic world)	Smart Cities and Places
Machine Learning/Comms	Natural Hazards (mapping and modelling)	
Computational Modelling	Smart and Sustainable Consumption	
Environmental Microbiology	Urban Green Infrastructure/Agriculture	
Electrical Engineering		

Of course, E3RI will in turn benefit from the E3LF. The E3LF has prepared the ground from which to grow a new type of graduate through offering trans-disciplinary laboratory and learning spaces for students to engage with each other and collide with scientists of different engineering, science and technology backgrounds. This kind of graduate is an ideal graduate to continue further education as PhD candidates in E3RI.

E3RI offers further value for Trinity through the deeper relationships it will foster with industry. This is important for two reasons: firstly, given the potential reduction in available research funding, new sources of research income are crucial for Trinity; and secondly links with industry create opportunities for graduates.

E3RI resonates with our ambitions around the European Universities Initiative. CHARM-EU is the European Universities network in which Trinity is involved. It is one of 17 European universities funded by the European Union through the first call of the European Universities initiative. Trinity's partners are University of Barcelona (Spain), Utrecht University (the Netherlands), Eötvös Loránd University (Hungary) and University of Montpellier (France). CHARM-EU will design and test a new European University concept through the creation of education and research programmes delivered across all partners and aligned with the United Nations Sustainable Development Goals, the European Green Deal and Horizon Europe Missions. The broad theme of CHARM-EU is *reconciling humanity with the planet*.

Overall, E3RI offers a real opportunity to deliver world class research facilities, to allow existing staff to fulfil their potential, to attract new talent, to allow us to compete for funding that we otherwise would not be able to, to continue to enhance research informed teaching, to provide opportunities for students, to build stronger relationships with industry, to engage with the community, and to tackle a challenge at scale that matters to people in Trinity and the world.

The Value of E3RI for Dublin and Ireland

E3RI also will be a superb value proposition for Dublin and Ireland as the core component of the proposed Grand Canal Innovation District (GCID). Details of GCID are found in its manifesto - https://www.tcd.ie/innovation-district/manifesto.pdf.

An innovation district is a dense, dynamic engine of economic activity where research-oriented institutions, high growth firms, and tech and creative start-ups are embedded within a growing, amenity-rich residential and commercial environment[2]. We need an internationally visible and credible innovation district in Ireland that will act as a magnet for talent, investment, innovation, industry and research. Ireland's global identity is not yet synonymous with innovation and that disconnect could turn out to be a significant threat. Successful innovation districts provide a unique set of co-located innovation, enterprise, social and cultural components. It is this overlapping of perspectives, cultures, skills and people that drives different thinking, improved collaboration and enhanced outcomes. Key ingredients include **world class university researchers** and **shared research infrastructure**, and **public facing outreach to engage with the local community and wider** among others.

E3RI will offer all of these.

E3RI will generate a concertation of research expertise in GCID, comprised of researchers from Trinity and, through partnerships, researchers from around the world. The world class research facilities will provide opportunities to provide national scale infrastructure that can give Ireland an edge. The location of talent and facilities in the Silicon Docks area will further attract companies and Foreign Direct Investment.

Trinity has a proven track record of success in innovation and entrepreneurship and has been ranked first in Europe (PitchBook rankings) for graduate entrepreneurship for the last five years. In addition, Tangent (Trinity's Ideas Workspace) provides award-winning educational and training programmes such as Blackstone LaunchPad powered by Techstars, which provides students with entrepreneurial support, and Ireland's first and most successful student start-up accelerator programme, LaunchBox). This will further feed into GCID and in so doing Trinity will be a catalyst for the innovation that happens there.

[2] 'Connect to Compete' Brookings Philadelphia Report, May 2017

Trinity's existing relationship with Dublin City Council will be strengthened through E3RI and GCID, and the openness of E3RI and its role in public engagement will play a significant part in engaging with the community.

More importantly still is the fact that relationships with other institutions in Ireland will be made through E3RI, opening up the opportunity for others to co-locate with us and have a strong presence at the heart of the Silicon Docks.

The idea for E3RI and the Grand Canal Innovation District has been in the making for some time. E3RI and GCID are needed now more than ever. Advancing solutions to issues such as climate change while simultaneously addressing the deep recession following the Covid-19 pandemic challenges us-as-scientists to think differently and us-as-entrepreneurs to do differently. E3RI, at the heart of GCID, can drive next generation of green industries on which our future economy can be based. Our combined vision for E3RI and GCID holds the potential to be a crucial element in how we kick-start the economy at the end of the current crisis[3].

[3] OECD (2020), *OECD Economic Outlook, Interim Report March 2020*, OECD Publishing, Paris, https://doi.org/10.1787/7969896b-en.

1 - Bringing Disciplines Together and Building on a Foundation of Excellence

In returning now, to looking at how we make E3RI a reality we look at the four different elements of what is involved. The first element is about bringing researchers in disciplines from across the divide of the natural and the engineered worlds together as part of our Engineering, the Environment and Emerging Technologies Research Institute. E3RI will, therefore, be one of the first research institutes globally to integrate engineering, technology and the natural sciences at scale to address the challenges of a liveable planet: to strive for balance between the natural world, the digital, the human, a thriving society, and a thriving economy.

The base of the E3RI research excellence is grounded in a wider E3 initiative that sees the Schools of Engineering, Computer Science & Statistics, and Natural Sciences come together. Added to this, E3RI will draw on a strong track record in nanomaterials, material science and social sciences. We can draw on Engineers, Computer Scientists, Statisticians, Botanists, Zoologists, Geographers, Geologists, Physicists, Chemists, and Social Scientists to pursue our research mission. This provides a very strong mix to tackle the fundamental issues of a liveable planet, the technological development that is needed for our economy and society, and the social behaviours that emerge or that need to be fostered.

This group of researchers brings with them a superb track record. They have a history of large-scale collaboration, are behind key initiatives that will inform E3RI, and have the ability to attract significant research funding. They also have a strong publications and citations record, an international presence, great relationships with industry and a keen interest in innovation.

A history of large-scale national and international collaboration. The cohort of researchers involved in E3RI have exceptional experience in large-scale collaboration and are well placed to work at the scale that would be expected in E3RI. Trinity is host to three national Science Foundation Ireland (SFI) research centres of significant scale (ADAPT, AMBER and CONNECT), all of which are under the directorship of academics involved in E3RI. Trinity is also significantly involved in a fourth national SFI centre (iCRAG), again involving academics driving the E3RI initiative and which also resonates strongly with the E3RI agenda. Each of these centres involve in the region of 200+ researchers, manage extensive research projects of national and international scale, work closely with industry, engage in technology transfer, and are hugely adept at public engagement.

ADAPT	The ADAPT Centre focuses on developing next generation digital technologies that transform how people communicate by helping to analyse, personalise and deliver digital data more effectively for businesses and individuals. https://www.adaptcentre.ie/
AMBER	AMBER (Advanced Materials and BioEngineering Research) is a Science Foundation Ireland funded centre that provides a partnership between leading researchers in

	materials science and industry. Current themes are Materials for ICT, Materials for Health, Materials for Energy, Engineered Functional Materials http://ambercentre.ie/
CONNECT	CONNECT focuses on future networks and communications with the aim of designing open communication systems that enable multiple services providers to share network resources as they compete to satisfy the demands of a diverse set of end users. https://connectcentre.ie/
iCRAG	ICRAG develops innovative science and technologies to better understand the Earth's past, present, and future and how people are connected to it. Themes include sustainable discovery of energy resources and raw materials required for decarbonisation, securing and protecting groundwater and marine resources, and protecting society from Earth's hazards such as flooding and landslides. https://www.icrag-centre.org/

Already, it is possible to see how the work of these centres is relevant for E3RI and the potential for bringing this expertise together.

Beyond these centres there are other large-scale collaborations that feed into E3RI. ENABLE is a spoke of a number of SFI centres-also operating at national scale.

ENABLE	ENABLE is addressing the challenges that currently limit the potential benefits of IoT for communities. This involves a focus on enabling smarter buildings, more efficient transportation/ mobility, better handling of environmental issues, stronger data privacy, and enhanced cyber and infrastructure security. https://www.enable-research.ie/

We are also part of key international networks that are led by academics involved in E3RI and are highly relevant for the E3RI research agenda. Trinity is among a very small number of universities involved in three of the 'Knowledge Innovation Communities' (KICs) established and funded by the European Institute of Innovation and Technology (EIT). Two of those are especially important to E3RI.

EIT Climate-KIC	EIT Climate KIC working to accelerate the transition to a zero-carbon economy and identify and support innovation that helps society mitigate and adapt to climate change. We believe that a decarbonised, sustainable economy is not only necessary to prevent catastrophic climate change but presents a wealth of opportunities for business and society. https://www.climate-kic.org/
EIT RawMaterials -KIC	EIT RawMaterials-KIC is the largest consortium in the raw materials sector worldwide. Its vision is to develop raw materials into a major strength for Europe. Its mission is to enable sustainable competitiveness of the European minerals, metals and materials sector along the value chain by driving innovation, education and entrepreneurship. https://eitrawmaterials.eu/

These networks (Knowledge Innovation Communities) have the potential to be used effectively within E3RI.

A plethora of existing initiatives within the university that will underpin the E3RI agenda. Within Trinity there are already a whole range of relevant initiatives run by

academics involved in E3RI, emphasising the fact that E3RI is built on substantial endeavour and experience.

CHIME	The Centre for Creative Technologies & Media Engineering (CHIME). CHIME brings together different groups: The Signal Processing Media Applications Group (Sigmedia) with research activities are centred on digital signal processing technology. We exploit knowledge from statistics, applied mathematics, computer vision, image and video processing, and speech and language understanding in order to solve very unique problems in a range of domains. The Graphics Vision and Visualisation group (GV2) at Trinity College Dublin (TCD) is an internationally active research group dedicated to carrying out innovative research in computer graphics, computer vision and all aspects of visual computing. V-SENSE is a team of 20+ researchers in Visual Computing at the intersection of Computer Vision, Computer Graphics and Media Signal Processing. We are building a dynamic environment where enthusiastic young scientists with different backgrounds get together to shape the future in fundamental, as well as applied research projects. https://v-sense.scss.tcd.ie/
Future Cities	The Future Cities Research Centre undertakes multi-disciplinary research that enables, promotes and facilitates behavioural change for sustainability. The research is supported by the application of sensor, communication and analytical technological solutions to sustainability concerns in urban infrastructure such as energy, water, waste management and transportation systems. https://www.tcd.ie/futurecities/
TCBE	The Trinity Centre for Biomedical Engineering focuses on research in medical devices and drug delivery, neural engineering, biomechanics and mechanobiology, tissue engineering and regenerative medicine https://www.tcd.ie/biomedicalengineering/
TCBR	The Trinity Centre for Biodiversity Research was launched in December 2008 by Sir David Attenborough. Based in the School of Natural Sciences, the TCBR brings together researchers from across TCD to provide a broad base of expertise in a range of biodiversity research areas, enabling research to cross traditional disciplinary boundaries to encompass biological, social, economic, legal and political aspects of biodiversity. https://www.tcd.ie/tcbr/
TCE	The Trinity Centre for the Environment acts as a hub for academics, postdocs, and postgraduates who work in the area of environmental science, or who wish to visit College in order to carry out research in a related area. The TCE comprises a wide collection of academic and research staff, as well as visiting and affiliate members. It also has extensive laboratories as well as space for visiting researchers. https://www.tcd.ie/environment/
TCEH	The Environmental Humanities at Trinity College Dublin aims to raise environmental awareness, perception and action through multi-disciplinary research and education. We collaborate through a cross-disciplinary lens and draw upon the insights of history, literature, philosophy, drama, film, media and culture studies, anthropology, sociology, psychology, geography, and other related disciplines. https://www.tcd.ie/tceh/
TCIH	The Centre for Innovative Human Systems (CIHS) is focussed on bringing together a range of perspectives to develop better ways of describing, understanding and effectively changing the complex human systems and processes we take for granted: transport, healthcare, security, education, finance, the internet, politics. Vast, complex, interdependent systems of individuals, organisations and technologies interact to innovate, design, develop, finance, regulate, certify, produce, test, localise, market, sell and deliver these to us. https://www.tcd.ie/cihs/
TRIP	The Centre for Transport Research and Innovation for People (TRIP) is a multidisciplinary centre based at TCD and has a link with UCC. It aims to develop and deliver cohesive and dynamic interdisciplinary research on a range of topics relating to

	Transport such as ICT in transport, solving urban congestion, quality of life, safety and the environmental impacts of transport. https://www.tcd.ie/transport-research/
TRISS	Trinity Research in Social Sciences (TRiSS) is a vehicle to support and advance world-leading research in the social sciences at Trinity by bringing together social sciences researchers from across the University. TRiSS currently represents 14 disciplines involved in social science research across 8 different schools. https://www.tcd.ie/triss/

A track record of attracting significant research funding. The cohort of academics associated with E3RI have attracted significant funding. The following figures are for the years 2015-2020.

The three initial E3 schools have performed as follows:

School (inc Research Inst)	*No. of Grants Awarded*	*Value of Grants Awarded*
Natural Sciences	151	€37.3M
SCSS	134	€67.3M
Engineering	201	€58.7M
TOTAL	**486**	**€163.3**

These amounts do not yet include renewal of the ADAPT and CONNECT centres which will take place before the end of 2020 and which will significantly increase this total.

Adding chemistry and physics to the mix (which takes AMBER into account) results in the following:

School (inc Research Inst)	*No. of Grants Awarded*	*Value of Grants Awarded*
Natural Sciences	151	€37.3M
SCSS	134	€67.3M
Engineering	201	€58.7M
Physics	178	€62M
Chemistry	126	€92.2M
TOTAL	**790**	**€317.5**

This performance is exceptionally strong and bodes well for the future.

26 of our highly prestigious European Research Council (ERC) awards are housed within these schools, and 11 of Trinity's top 20 Principle Investigators in terms of research income are included in this mix.

A strong publication & citations record. The researchers from the Schools associated with E3RI produced over 3,000 scholarly outputs between 2014-2018. The quality of these outputs was considerably higher than the world average with a field weighted citation impact of 1.56 and a citation count in excess of 34,000 for this period. Of these 3,000+ publications, 42.6% were published in the top 10% journals worldwide, while 16.7% of these publications are in the top 10% most cited worldwide.

This group of researchers incorporate a broad range of expertise and cover a range of subject areas. The breakdown in scholarly outputs by subject area is shown in Figure 4:

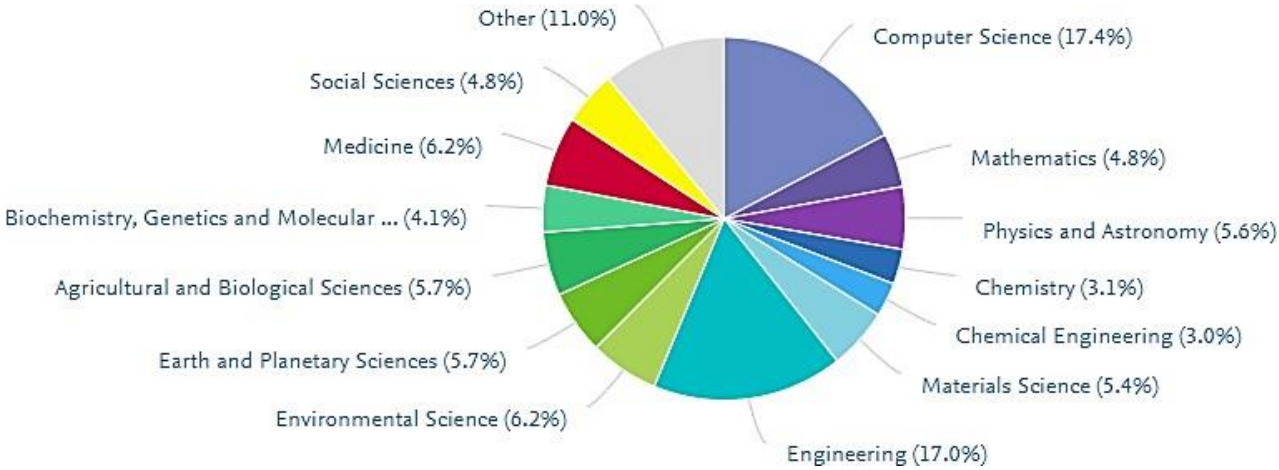


Figure 4: Breakdown of scholarly outputs by subject

An international presence. In addition, 47.7% of the 3,000 publications captured for this group are co-authored with researchers in other countries. These collaborators span the globe, with the UK as the top collaborating nation for E3 researchers, with eight organisations in the top 20.

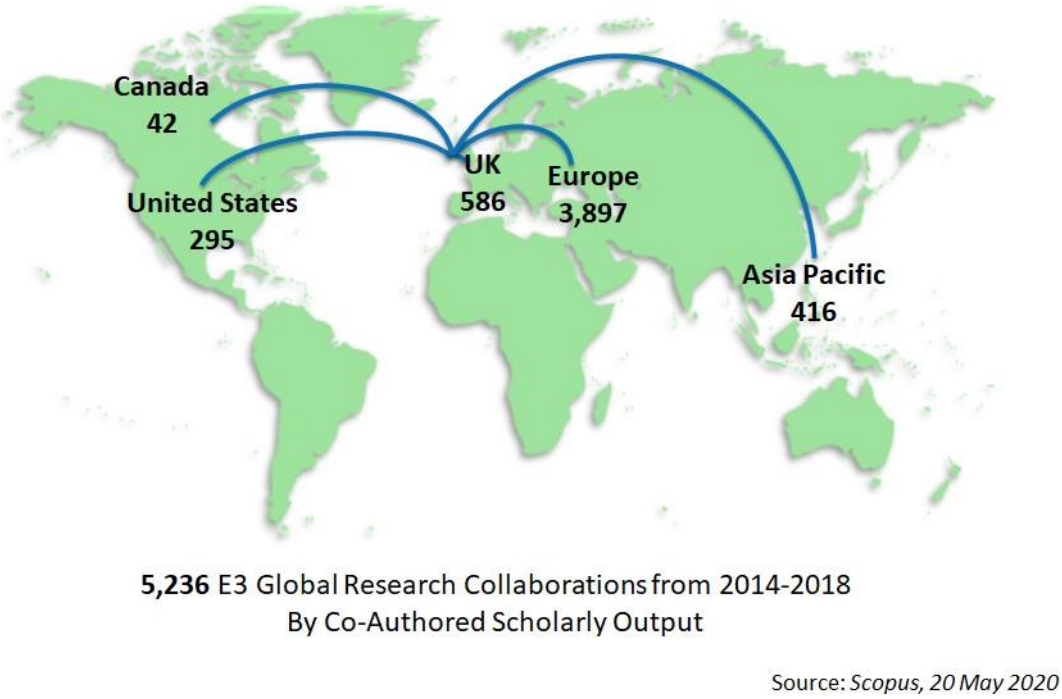


Figure 5: Global Collaborations of Researchers involved in E3RI between 2014-18

A deep understanding of engaging with industry. The academics involved in E3RI have a long history of working with industry and a deep understanding of building

relationships with enterprise. The breath of companies with which this cohort is involved is impressive.

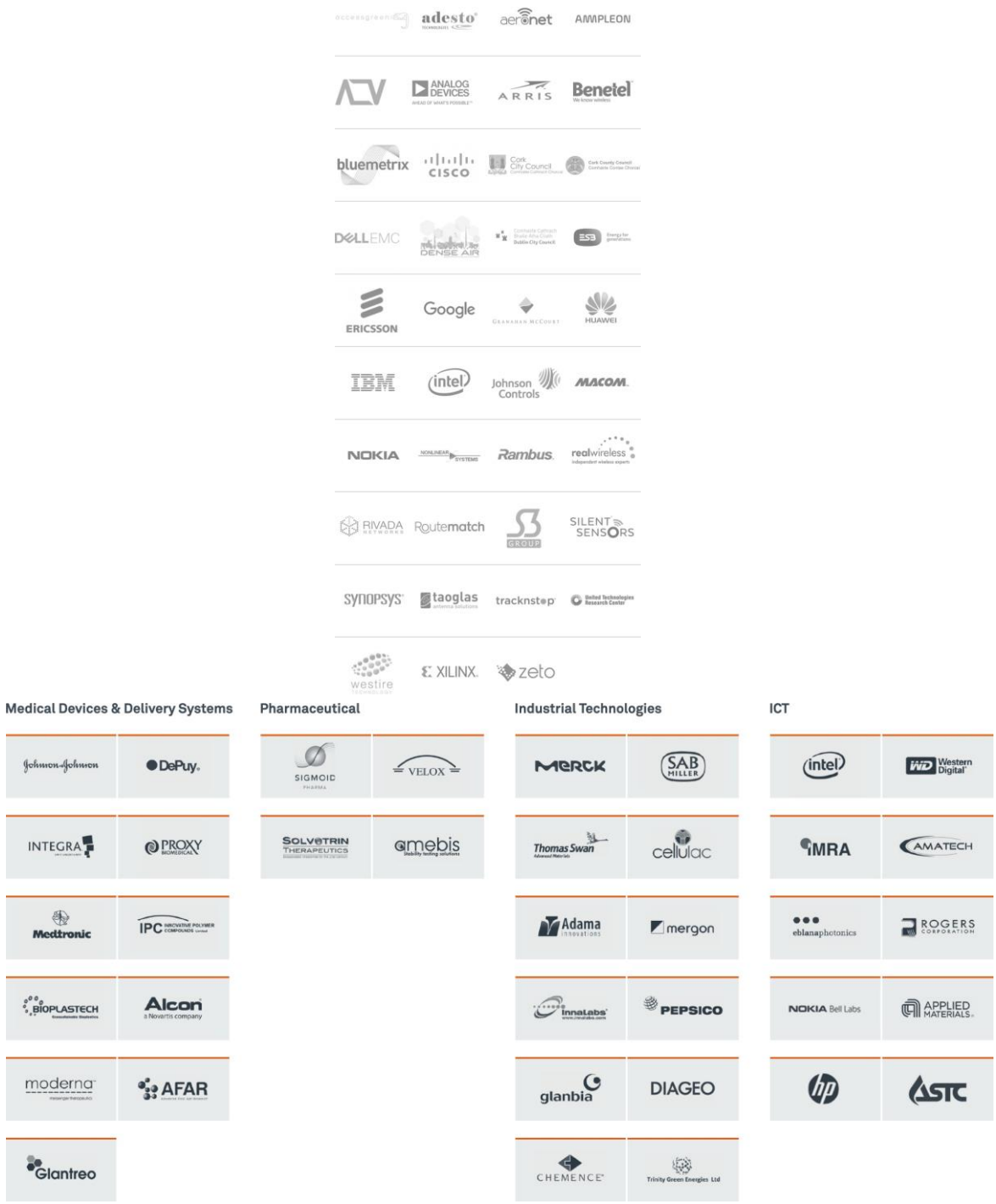


Figure 6: Examples of existing companies, with which we partner

Note – we engage with many more companies than the above samples

A sustained interest in innovation. There is a culture of innovation within the E3RI cohort. One of the ways that this has been obvious is in the 35 spinouts that have been founded. This does not capture the successes of our graduates who go from these Schools to found their own companies – names such as Movidius, Havok, Swrve, Intercom and Iona Technologies spring to mind among many others.

35 Spin-Outs			
CrewFactors Ltd	Miravex Ltd	Silvercloud Health (NDRC Hybrid)	TOSCA Human Factors
CroiValve	Newgame Technologies Ltd (NDRC Hybrid)	Soapbox Labs	Transpharmation Ireland Ltd
DANALTO	Personalotels Ltd	Software Radio Systems Ltd	TriMod Therapeutics Ltd
Data Chemist	PixelPuffin Ltd	Solvotrin Therapeutics Ltd	Trinity Brain Health
EmpowerTheUser Ltd	Proverum	Sonitus Systems Ltd	Trinity Green Energies Ltd
Eneclann Ltd	Scientific Resources Ltd	Swirl Generators Ltd	Trinity Stamina Ltd
Glanta Ltd	SelfSense Technologies Ltd	Tolerant Networks Ltd	Volograms
			Xcelerit Computing Ltd

In addition, 147 Enterprise Ireland Innovation Vouchers have been serviced by the researchers associated with E3RI, ensuring that the skills of these researchers are shared with Irish SMEs.

What we have here is merely a snapshot of the achievements of the researchers involved in E3RI. The numbers tell a small part of the story. There are many more achievements of which to be proud.

2 - Taking a Challenge-Based Approach

The second element to making E3RI a reality revolves around taking a radically different approach to problem-solving. The breaking down of silos between disciplines and the fostering of deep collaborations across the disciplines is the first step in that approach. This will inevitably lead to different combinations of expertise coming together to work on projects, to write papers or to apply for funding.

However, rather than just foster interdisciplinarity through co-location of different disciplines, E3RI will go a step further and adopt a *challenged-based approach* to bringing disparate perspectives together around a common goal.

E3RI is founded on the belief that the inter-dependence between the natural world and the economy can and must be a productive one. It is a belief that we can evolve technically and at the same time work in harmony with the world, that the circular economy can work at scale. Broadly speaking the challenges will relate to reconciling a vibrant economy with the well-being of the people and the planet, will resonate with the existing breath of expertise involved in E3RI, and expand as the expertise and partnerships grow. We have learned from the Covid-19 pandemic during which different research expertise was harnessed in a very agile fashion to respond to a crisis. That responsiveness to a challenge, the creative thinking involved, the adaptive approaches and the nimble way in which all of this research was done is admirable. The challenge-based approach is about capturing this spirit and creativity.

Crucially, we do not see working in a challenged-based fashion equating solely with working on applied research problems. Setting common challenges across E3RI will open up new avenues for basic and fundamental research as well as applied research projects. Radical and disruptive thinking will be needed as well as strong systematic evidence.

We will adopt both a top-down and bottom-up approach to identifying grand challenges. In top-down situations we will respond to external calls, funding opportunities, and national or international needs. We can also invite challenges from partnering industries. The challenge-based approach to funding is increasingly common and there are increasing numbers of opportunities in this space. The European Green Deal, for example, will open up opportunities in this regard. The European Green Deal is a set of policy initiatives brought forward by the European Commission with the overarching aim of making Europe climate neutral in 2050. The EU's Green Deal is the over-arching policy framework which will guide the work programme of the new European Commission. EU Commission president Ursula Van der Leyen has spoken of it as being a European moonshot, with "the goal of reconciling our economy with our planet". This goal resonates exceptionally well with the E3RI.

In bottom-up scenarios we will develop our own challenges. We have already started this process through creating an *ideas bank* - a digital repository of the ideas generated

individually and collectively by researchers involved in E3RI. Ideally, we will also have internal competitive funds to support these challenges.

In our initial explorations we identified some sample challenges that play to the strengths of the team and revolve around looking for that balance between the natural world, the digital, the human, a thriving society, and a thriving economy. The headline questions for some of these are listed here.

How do we use the 70-80% of wood that is wasted when wood is harvested?
How can we properly measure biodiversity on the planet?
Can we build a smart- garden? Can plants' innate sensing capacity be harnessed for large spatial scale and long-term environmental monitoring?
How do we design the technologies and systems for the capture, storage, and conversion of carbon-dioxide into liquid fuels for energy generation and manufacturing applications?
How can we use Artificial Intelligence alongside emergent digital monitoring technologies to better understand highly non-linear environment-society interactions?
How do we build trustworthy AI Governance?
How do we create an on-demand shared public transport system?
How should we shape the evolution of cities to best reconcile the needs of humans with the sustainability of the planet?
How do we design new technologies and systems using our existing and developing knowledge of human behaviour?
What new and evolving social systems (energy markets, legal frameworks, business models, financial systems, economic systems, political systems) will we need to successfully deploy new technologies and systems?

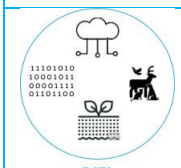
As can be seen from this short set of examples, these challenges call for both fundamental and applied research and would make excellent use of some of the shared research facilities described in this instantiation of E3RI.

In solving a challenge, of course the question arises as to what a good solution might look like. We talk about striving for balance between the natural world, the digital, the human, a thriving society, and a thriving economy. We use the phrase *balanced solutions for a better world*. The idea of a *balanced solution* therefore needs expanding.

Essentially, we believe we can strive for balanced solutions through systematically assessing all of the research endeavours on which we embark from six key perspectives. These perspectives are environment, production, resources, data, well-being and communities. The E3RI definitions for these terms are nuanced, go beyond traditional definitions, and very much embrace the physical and digital world.

These six perspectives are key to understanding what a balanced solution is. Based on these, we contend that a 'balanced solution' will ultimately act to benefit the environment, use resources responsibly, take account of implications for production,

manage the data consequences, further wellbeing of all life on earth, and recognise the implications for and role of communities. In other words, this is what we mean when we espouse '*balanced solutions for a better world.*'

Perspectives	
 ENVIRONMENT	Any solutions we explore must be thought through from an environmental impact perspective. The environment, our natural capital, underpins bio-based industries, human health and wellbeing, food security and the healthy functioning of our planetary support systems.
 PRODUCTION	A production perspective takes a complete life-cycle perspective and understands how goods and solutions are created, become obsolete, and their end of life processes, are reused in new products or are returned to nature sustainably. In E3RI we understand production in its broadest sense and include all sorts of manufacturing processes, and all sorts of physical and digital products, and natural and synthetic products. We are also interested in changing modes of production, 3D/4D printing, VR/AR modes of production etc.
 RESOURCES	A resource perspective calls for a deep understanding of the implications of any solution on resource usage, recognising limits on supply, and use of the circular economy. Moreover, in considering resources we move beyond the view of resources as those harvested from the planet and believe it is important that resources can be thought of from digital as well as physical perspectives.
 DATA	A data perspective brings with it an understanding of what data is needed, how data might be captured and secured, as well as data privacy issues and the ethical use of data. In E3RI we think of data in its fullest form. We do not limit our understanding to 'digitally acquired and stored' data but include seed banks, plant banks, data embedded in the natural landscape and more. A data perspective also requires us to consider what needs to be preserved for posterity.
 WELLBEING	A wellbeing perspective seeks to understand how our design choices and technical developments contribute to or adversely affect wellbeing.
 COMMUNITIES	A community perspective aims to understand the impact of the solution on the wider community. It brings in ideas of scale and asks the question as to whether the solution is appropriate for the scale at which it is needed – e.g. local or global community. It asks us to consider human behaviour and whether a solution will in fact take root.

3 - Working in Partnership with Industry & Other Institutions

The third element in making E3RI a reality is partnership. Key strategic partnerships will ensure that E3RI carves out a very strong national and international identity.

E3RI will a generate a critical mass of researchers working on key research topics in engineering, the environment and emerging technologies, as well as responding to challenges that ensure the inter-dependence between the natural world and the economy is productive. Industry is constantly innovating, deploying emergent technologies to both anticipate and respond to market and regulatory pressures. For both industry and academic innovators, challenges such as climate change present opportunities for transformative advances in all technologies. To really inform, impact, change, and disrupt economic activity so that we can create a more productive inter-dependence, we will need to fully and wholly engage with each other.

The location of E3RI will afford us the opportunities to do this in a profound way. We will be surrounded by industry, and we will also have the option for inviting specific industry partners to be part of E3RI. Ideally, we want to engage with industry on fundamental as well as applied research projects and want to build strong long-term relationships. We can build on the expertise around industry engagement we have to date, especially that expertise that has come through AMBER, ADAPT and CONNECT.

There are a broad range of options for what that engagement can look like and it will be up to us and industry partners to determine what works best.

In the first instance there are opportunities for creating collaborative research programmes, funded by industry or co-funded by the state or other funders. In looking forward to Horizon Europe we see a much greater role for industry (e.g. in the Innovation pillar). Meaningful relationships with industry to respond to these kinds of funding calls is crucial. We can also consider contract research opportunities.

The examples thus far represent standard modes of engagement. We want to go much further. The table below presents a number of options that will build greater engagement with industry. The options include ones that are based on deep immersion of industry within E3RI to more light touch scenarios.

Industry Researchers in E3RI	
Professors of Practice	An opportunity to encourage companies to attract or second leading researchers in their organisation to Dublin to take a faculty post at Trinity for a period of time.
Entrepreneur-in-Residence	An opportunity for entrepreneurs and Trinity graduates who have succeeded in growing businesses to come back to mentor start-ups, campus companies, student companies and to provide inspiring case studies in the classroom or based within accelerators or incubators.

Investor-in-Residence	An opportunity for experienced venture capitalists to support start-ups, campus companies and student companies as they raise funding and look to scale.
Co-location of industry research teams	An opportunity to base researchers from industry in E3RI on a more long-term basis – to facilitate the kind of collaboration that comes from close proximity and easy exchange of ideas.
Use of E3RI Research Facilities	An opportunity for industry-based researchers to use E3RI facilities.
Co-Programming in E3RI	An opportunity for E3RI staff and students to programme events, seminars, workshops, design sessions with industry in E3RI.
Thought-Leadership	An opportunity to co-fund think tanks that involve industry leaders from around the world.
Hosting Industry Bodies	An opportunity to host key industry bodies – IBEC like entities, standards bodies etc.
Providing space for Industry activities	An opportunity for industry to host their own meetings and events in E3RI

Through strong partnerships with industry there will also be opportunities for E3RI researchers in industry:

E3RI Researchers in Industry	
Researchers in Residence Programme	An opportunity to for academic staff and postdoctoral researchers to get experience working in Industry
Internships Programme	An opportunity for final year, MScs or PhD students from E3LF, to do internships
Sponsored PhD / Masters Programmes	An opportunity for industry to sponsor PhDs and MScs and have those individuals be based in industry

There are many options that we can explore for how we formalise the arrangement between E3RI and industry. We can, for example, use a membership model that allows access to library, seminars, shared laboratory infrastructure, graduating students and early look at research findings, IP and commercialisation opportunity. We can also work on an individual project/opportunity basis. As part of all of this we can create a revised IP policy for E3RI partners for fully funded projects if the scale and duration of partnership is attractive.

The partnerships we speak of for E3RI do not stop with industry. It is important we also build partnerships with other academic institutions. The kinds of challenges we want to tackle are complex and large. E3RI and GCID can provide a focus point for coming together at a national level to build even greater scale. To this end we have been working with colleagues in other Higher Education Institutions in Ireland.

We also believe that there is a huge opportunity to partner internationally around E3RI and for key academic institutions to have a footprint here in Ireland. We are currently exploring possibilities that can bring strategic value for all involved.

Beyond industry and academia, E3RI will build other partnerships with the local community, with civil society, with policy makers, and the wider world. These kinds of partnerships are not simply nice to have; they will play a crucial role in the research we

do. Fully understanding the challenges we aim to tackle and effecting change through solutions, makes this a necessity.

4 - Building the Infrastructure to Match the Vision

The fourth element to make E3RI a reality is a most important one: the creation a building that matches the needs of E3RI and the subsequent occupying of the building in a manner that creates the collaborative environment we desire.

Our requirements are world class research facilities for supporting research related to engineering, environment and emerging technologies. The research facilities need to support the worlds of natural science, computing, high-tech, engineering, material science and social sciences etc. Interdisciplinary collaboration is key, and space should exist that facilitates interaction, meetings, group work, ideation and more so that we can come together around common challenges. The latter is especially important. The E3RI vision is based around the coming together of different disciplines and around the balanced solution approach, an approach that calls for the mixing together of multiple perspectives. The E3RI building must give physical form to this level of integration.

Partnerships need to be facilitated and need to be accommodated in shared office spaces. Designs need to take into account the time taken for the project to materialise and have a level of reconfigurability that allows us to adapt with changing research practices. Ultimately sustainability should feature heavily in the design.

We are not yet at design stage but have conducted a high-level feasibility study to understand the broad parameters of these demands.

Perkins & Will were appointed for the purposes of carrying out this study, and with them we looked at three kinds of space. Firstly, and most importantly, we looked at space for labs and research facilities. Secondly, we looked at what is broadly termed activation space and includes space for collaborations, meetings, events and other activities. Thirdly we briefly looked at office space.

Research Facilities / Lab Space

The process of exploring research facilities and lab space began with observation of world trends in design and creation of research labs.

Bringing different disciplines together to develop solutions is very much on trend with what is happening around the world. Disciplines are brought together because innovation is more likely in novel combinations of knowledge than in the extension of existing knowledge[4]. The E3 approach extends further this by using multiple perspectives to test the balance of a solution – an extension that draws on broader

[4] Uzzi, B., Mukherjee, S., Stringer, M., & Jones, B. (2013). Atypical combinations and scientific impact. *Science, 342*(6157), 468-472.

insights and expertise. Perkins & Will use the phrase convergence[5] – the merging of approaches and insights from historically distinct disciplines such as engineering, physics, computer science, chemistry, mathematics, and the natural sciences – to describe way the different disciplines in E3RI come together.

Achieving the necessary convergence of ideas has implications for the space in which those ideas are generated. Perkins & Will point out that the era of true singular discipline research buildings has ended and the era of convergent - melding of traditionally separated disciplines - research buildings is well underway.

To deal with the demands of convergence and of the drive towards highly collaborative spaces they note:

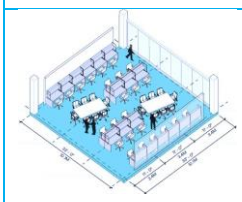
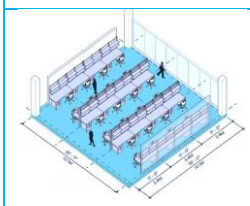
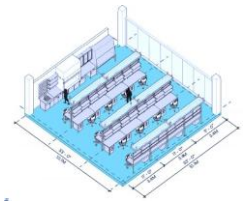
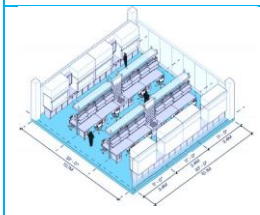
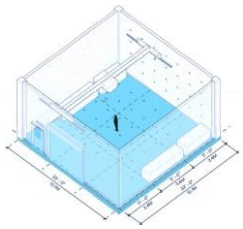
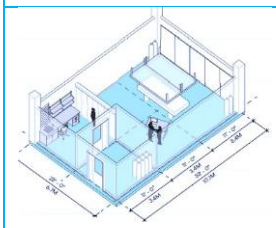
- As we move into the next-generation of research spaces, single-discipline focus laboratories and clearly defined research needs are less and less common. Instead, we are seeing spaces that will greatly vary in their research usage and require greater flexibility to accommodate a broader range of activities over time.
- Increasing convergence also shows a dramatic increase in the demand for computational space. As mixed discipline work becomes more common, data-based techniques from other fields are moving into scientific research, increasing demand for spaces for theoretical and computing research work. And as computer power becomes more robust and ubiquitous, and computational modelling techniques become more precise and representative, more and more research projects include computational methods.
- In many cases, even experimental projects now use a mix of both physical experimental work and theoretical / computational work. Consequently, there are strong demands both for more computational research space and for computational space to be located adjacent to experimental research laboratories.

However, alongside these trends at the other end of the spectrum, we see a focus on specialist spaces. To this end, Perkins & Will note:

- There is an increased demand for both specialized laboratories and research core facilities. Specialized, or "High Performance", labs provide researchers with purpose-built controlled environments that can deliver precision results.
- Core facilities centralize increasingly expensive and complicated research tools into shared resources. Centralizing assets allows more researchers access to newer and better tools, while lowering costs, increasing safety, and reducing risk.

Taking all of these trends into account and based on our specific needs, Perkins & Will defined 6 prototype labs that provide a general framework for the type of labs that will be part of E3RI. These labs range from the more general ones that support all sorts of computational activities, to the highly specialised labs supporting sensitive equipment, as reflected in the trends.

[5] This term originated in MIT - Sharp, P. A., & Langer, R. (2011). Promoting convergence in biomedical science. Science, 333(6042), 527-527

Prototype Lab	Terminology & Description	E3RI activity that might be supported in this lab
	Computational Minimal infrastructure needs in terms of gas, structural strengthening or abuse-resistant finishes. Data and power provided from the ceiling to provide maximum flexibility.	Studio Lab (depth sensors, professional lights, motion capture, 3D scanning, green screen, flexible staging etc.) Write-up space for Post-docs and PhDs Shared workspace for admin and technical staff
	Dry Lab Open Flexible space with moveable / removeable lab benches of furniture. Services (power, data, gas) provided from the ceiling to allow maximum flexibility	Electronic and electrical engineering: Electronics Assembly Testbed Instrument labs: Chromatograph Elemental Analysers
	Wet Lab Traditional lab with relatively few fume hoods and equipment on the perimeter walls. Service infrastructure (gas, power, data) provided from ceiling & perimeter wall and centre zine equipped with moveable benches to provide maximum flexibility	Botany Zoology Geology Environmental Science
	Heavy Wet Chemistry More fume hoods distributed through the lab space, and more abuse-resistant finishes on floor and bench surfaces to deal with higher level of chemical hazards or bench-mounted equipment that requires ventilation	Materials Science: XRF analyser Thermal Analysis equipment Environmental Science: Wastewater treatment lab Spectrophotometer Geochemistry
	High bay / Heavy High Bay Large open area (double or triple height) with robust structure and industrial features - large roll-up doors, extreme abuse resistant finishes, etc. Infrastructure can be tailored e.g. – active walls, strong floors, structural hard points, pits, central hydraulics, cranes, high voltage power, etc.	CAVE (Computer Assisted Virtual Environment) Visualization Lab Climate Simulators 3-D printers Workshop Maker space Civil / Mechanical / Geological materials testing
	High Performance Specialist controlled environments with features that vary according to needs – particulate free, controlled environment (temperature, humidity, light), electromagnetic shielding, low vibration, acoustically quiet	Anechoic Chamber Electron Microscopy X-Ray analysis LASERs

Activation Space

Activation space is the term used by Perkins & Will to describe all spaces used to come together, meet, collaborate, hold events etc. To encourage deep levels of collaboration this kind of space is important and should be intentionally designed. Perkins & Will encourage the use as of much space as possible for interaction. In traditional buildings circulation space like corridors and staircases is only designed for passing through. However, current design practice can expand corridors to accommodate linear cafes and create study nooks and booths on staircases. In this way, circulation space serves many purposes. Perkins and Will's benchmarking studies also highlight the increased value of public space (as activation space) in academic buildings. Even campus-bound buildings expected to have little engagement outside the university community reserve 15% – 20% of usable internal space for open access.

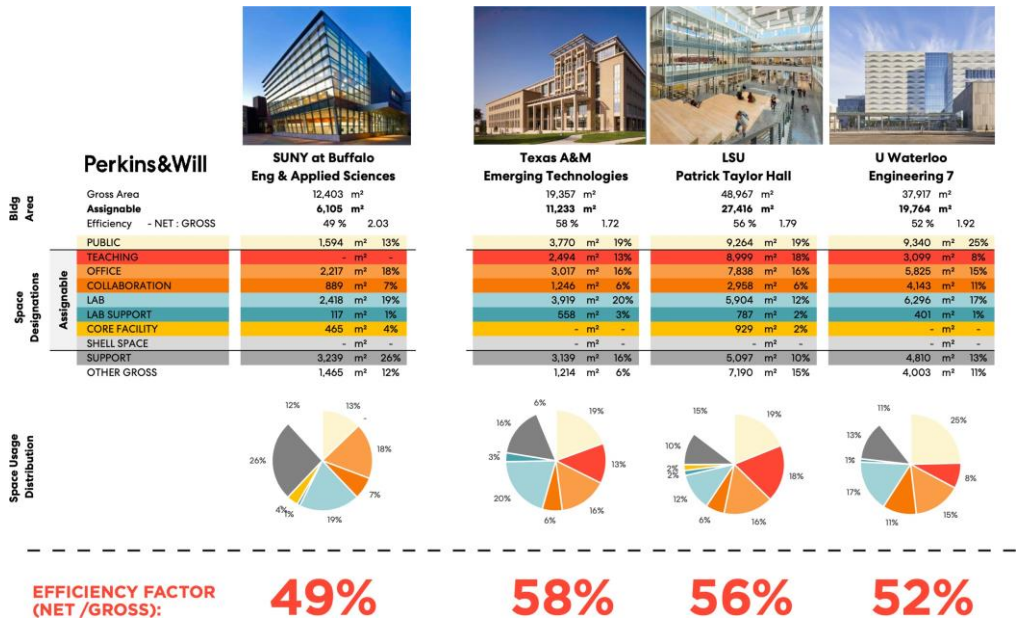
Office Space

Perkins & Will highlight that office space - write-up space for PhDs and postdoctoral researchers, office space for support staff, or individual academic offices - can be considered as a form of lab. The least intensive lab in their typology provides power and data but no additional infrastructure. It is a multi-functional space that can serve as offices for staff as easily as labs for theoretical and computation-based research, data visualization, or computer-assisted virtual environments. In the modular approach they propose a standard lab/office unit would be shared space for between ten and twenty people. Two or more modules can be joined together to create larger open plan workspaces. Alternatively, individual modules can be partitioned into smaller spaces, right down to individual spaces. The modular approach provides a flexible grid that allows space to be converted quickly and efficiently so it can adapt over time to suit changing needs.

A Comment on Assignable Space

The final crucial aspect of the Perkins & Will high-level feasibility study relates to guidance around building size. A building that matches the needs of E3RI is a building that is built for science research. One crucial observation is that the assignable space (the internal area available for use) in these types of buildings is a much smaller percentage of the total building size than the assignable space of a building that is used for teaching or office space. Efficiency analysis of science buildings around the world yield figures in the region of 49-58% as compared with 70-80% of office or teaching buildings.

To create a building that meets the needs of E3RI, these efficiency factors must be taken into account.



Perkins&Will	SUNY at Buffalo Eng & Applied Sciences	Texas A&M Emerging Technologies	LSU Patrick Taylor Hall	U Waterloo Engineering 7
Bldg Area: Gross Area	12,403 m²	19,357 m²	48,967 m²	37,917 m²
Bldg Area: Assignable	6,105 m²	11,233 m²	27,416 m²	19,764 m²
Bldg Area: Efficiency - NET : GROSS	49 % 2.03	58 % 1.72	56 % 1.79	52 % 1.92
Space Designations: PUBLIC	1,594 m² 13%	3,770 m² 19%	9,264 m² 19%	9,340 m² 25%
Assignable: TEACHING	- m² -	2,494 m² 13%	8,999 m² 18%	3,099 m² 8%
Assignable: OFFICE	2,217 m² 18%	3,017 m² 16%	7,838 m² 16%	5,825 m² 15%
Assignable: COLLABORATION	889 m² 7%	1,246 m² 6%	2,958 m² 6%	4,143 m² 11%
Assignable: LAB	2,418 m² 19%	3,919 m² 20%	5,904 m² 12%	6,296 m² 17%
Assignable: LAB SUPPORT	117 m² 1%	658 m² 3%	787 m² 2%	401 m² 1%
Assignable: CORE FACILITY	465 m² 4%	- m² -	929 m² 2%	- m² -
Assignable: SHELL SPACE	- m² -	- m² -	- m² -	- m² -
SUPPORT	3,239 m² 26%	3,139 m² 16%	5,097 m² 10%	4,810 m² 13%
OTHER GROSS	1,465 m² 12%	1,214 m² 6%	7,190 m² 15%	4,003 m² 11%
Space Usage Distribution				
EFFICIENCY FACTOR (NET /GROSS):	49%	58%	56%	52%

Figure 7: Figures from Perkins & Will showing trends in different research institutes to illustrate the percentages of usable space versus gross size

Brining it All Together

Ultimately E3RI will have three broad types of space. Firstly, there will be cutting-edge shared laboratories as defined by the prototypical spaces. Secondly, there will be activation space for supporting collaboration, meetings, events, interaction and more. Thirdly, there will be office space which can support individual and shared scenarios. The Perkins & Will high-level feasibility study offers a broad framework which we can populate and can use as a guide to what can be created and what is feasible.

The exact shape of E3RI has yet to be defined. However based on the learnings to date, we can say in broad terms that 50% of the space will be given over to shared laboratory facilities, 25% of the space it offices and work stations and 25 % to activation space. The latter will be used for collaboration, meetings, programming as well as for interacting with the wide community and the public.

Through workshops and deep engagement with the different stakeholders in Trinity, different examples of how the shared laboratory facilities might be configured are being developed. These details will be available of the E3RI research pages.

Figure 8: Potential makeup of E3RI. Exact design of labs under development

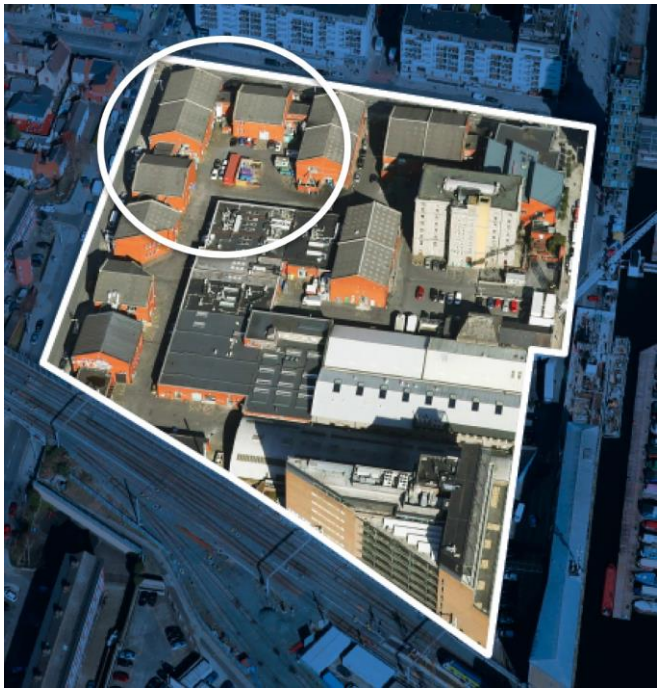


Figure 9: Approximatel location on TTEC

E3RI Governance

An institution as ambitious and as bold as E3RI will need to have governance to match. There is some way to go before fully determining the exact structure that makes sense. How research is organised within E3RI might impact the governance structures. The underlying business model that will support the operation of E3RI as a dedicated research building may also have an impact. Following on from Board input and further development of the E3RI strong governance will be defined.

E3RI Research Organisation & Funding Model

A major challenge for E3RI is the funding of the institute. We need to fund the yearly operation of the building itself, which will not be inconsequential, and secure funding for the research we carry out within E3RI.

The research will be mainly funded through the E3RI academics securing competitive research awards. The stellar track record of the cohort involved in E3RI points to a successful future on this front. The operation costs for E3RI will relate to the running and maintenance of research facilities, salaries for specialist support and operations staff, general building running costs and more. However, the way research is funded in Ireland and the EU does not lend itself to covering all of the operation costs involved.

To generate additional income for the operation of our research facilities we oftentimes look towards increasing student numbers. This may not be an option for E3RI as increased student numbers in the original E3 Schools are linked directly to the business model for the E3 Learning Foundry. We will have to think differently. To do this we may need to rethink how research is organised within E3RI.

Potential Research Organisation Strategies

Broadly speaking there are three main archetypes for how research can be organised.

1. PI Group Based Organisation – *Research Home*

One way of organizing research institutes is around the Principle Investigators. In this model the institute is the research home for academic staff and houses the PI's 'group'. The size of a PI group – measured by number of postdoctoral researchers, Ph.D candidates and masters students – can vary significantly depending on the level of external funding available, the value of funding secured, and the career stage of the PI. We use the term 'group' loosely here. For example, it is possible to think of the members of an SFI Research Centre as 'one group' that would be housed with the Centre Director,

though of course the SFI Centre can also be broken down into co-PIs and their individual groups.

When there is substantial funding for the field of inquiry, the size of an established PI's group and its infrastructure needs can be predicted with a degree of confidence. When the funding level is stable the institute can be configured to make efficient use of resources.

However, in reality research funding is unstable. PI groups expand when grants are secured and contract in the periods between grants. To maintain efficient operations a certain level of dependable funding is required to maintain capacity in the troughs.

Additional challenges of organizing research around PI groups include issues like core facilities being duplicated in several PI labs, challenges around redeploying space that is considered to be belonging to that PI, or reconfiguring labs to extend into exploratory areas for which there is not yet funding. This model also depends on the generosity of the PI to provide infrastructural support for early career researchers.

2. Facilities Based Organisation – *Research Hotel*

An alternative to providing bespoke facilities around individual research needs is to invest in state-of-the-art facilities that will attract cutting edge researchers. In the research hotel model, infrastructure is centrally owned, maintained, and serviced. Access is open to all and provided on a pay-as-you-use basis. Subsidized access can be granted to academic and industry partners while non-partners pay commercial rates. Typically, commercial users expect a more comprehensive 'concierge' service, with significant support.

For academic users, some services are considered as training and skills development for earlier career researchers (e.g. sample preparation, instrument calibration carried out by PhD students).

In this model the institution takes on the majority of the risk for the development and running of the facilities. A key assumption is that there is sufficient provision for equipment access in grant funding, and the primary challenge is in securing sufficient usage levels to cover the costs of running, maintaining, and upgrading facilities and equipment.

3. Project Based Organisation - *Matrix Structure*

Research activities within institutes are often structured into projects, each led by an academic. The projects might be identified along discipline lines, either as Schools or Disciplines. Alternatively, projects might be multi-disciplinary groupings described as domains or challenges. It is common to see these two organizing principles depicted as a matrix structure where one axis represents the long-term established structures (e.g. Disciplines) and the other shorter-term structures (e.g. challenges, themes, projects). The assumption is that established structures provide stability while short-term structures allow for adaptation.

The principle challenge of the matrix structure is that the replication of the hierarchical structures inherent in the long-term structures (e.g. Disciplines) constrains the ability to restructure nimbly to take advantage of new funding opportunities. Cross cutting elements create path-dependencies making it difficult to re-organize in order to explore emerging disciplines and to bring in the novel expertise and perspectives needed for innovation.

The Blended Reality

Archetypes can be useful devices for describing the high-level organising principles but are too simplistic to articulate the complex architecture of research organisation. In reality, research institutes are structed in such a way as to blend elements of several archetypes.

In some institutions the adaptation is simple. For example, the Centre for Structural Systems Biology is structured principally around 10 individual PIs or Group Leaders, each with a 'home' in another institution. However, 20% of the lab space is reserved for early career researchers who can apply for a 5-year residency while they transition from postdoctoral to independent PI. Group sizes range from two to 23 with larger groups also having responsibility for one of the shared core infrastructures and its associated technical and support staff.

Some institutes incorporate structural features from more archetypes and blend them in complex ways. For example, research at the Francis Crick Institute blends bottom-up and top-down structures to take advantage of the efficiencies of strategic direction without incurring opportunity costs by locking in research to defined fields. It is predominantly organized into PI Labs (107) which are limited in size to 12 and are grouped into one or more of the 23 Research Topics. However, research group members can elect to join one or more Interest Groups which host seminar series (open seminars are to accessible by the general public, closed seminars are for Interest Group Members only).

In the Crick tenure for a PI is limited to 12 years. The permanent research faculty are expanded and enhanced by visiting faculty who may opt to move their group to the Crick for a defined period (secondment) or spend a short period working at the Crick (attachment) while remaining an employee of their home institution: Secondments / attachments. Additional churn is enabled by the fact that any faculty member in a partner institute with interest in any Interest Group can apply for annual membership of that group for themselves and up to two members of their research team. This membership requires participation in all closed seminars hosted by that interest group.

In the case of both CSSB and The Crick, the institutes are multi-institutional partnerships which provide access to core infrastructures for their faculty that are also available to external parties.

Ultimately E3RI will comprise some kind of blend of these archetypal structures. Once determined that mix will also set parameters for the governance structure.

A Research Organisation Strategy for E3RI

While we have not yet set the structure for how research might be organised in E3RI, we have created a manifesto focused on the principles of the building itself and how it should be occupied. The Space Manifesto was created through a series of workshops involving different E3RI stakeholders and is focused around 4 key high-level principles, each of which is expanded in detail in the Space Manifesto Document.

1. We will design E3RI to enable world-class research
2. We will design E3RI in a radically sustainable way
3. We will design E3RI to promote collaboration and creativity
4. We will occupy E3RI responsibly

The first high-level principle underscores the fact that the building must be designed to allow us to compete globally. The second principle, designing of E3RI in a radically sustainable way, affords us the opportunity to live the change that we want, to turn the design and building of E3RI into an opportunity for a research project, and to use E3RI as a way to teach. The third principle relates to how the building is constituted to support the needs of a very collaborative, convergent research space. The fourth principle is about use of the building once built, and this speaks to the organisation of research. The following are some pertinent extracts from that section of the Space Manifesto.

We Will Occupy Space Responsibly

How we occupy space matters and the E3RI is as much a social project as it is a capital project. We have many legacy issues in Trinity with people occupying space they no longer need and others bursting at the seams. All of our research space tends to be linked to Schools making it complex to do collaborative initiatives. Overall, we think of space in a very static manner and do not think of it from a time perspective. In addition, we face financial challenges in terms of maintaining and running spaces, so we also need to think about occupying space from the perspective of shared support services. This type of approach will require a significant culture change.

Space should not be the static property of Schools but be driven by the dynamic needs of research - While PhD candidates and postdoctoral researchers would need a work 'home' for the duration of their degree or project, their supervisors and PIs should not be allocated permanent desks in E3RI. This may mean, for example, that space use is reviewed on a 3 or 5-year cycle in tandem with regular review of the research program.
There should be no entitlement to contiguous space - While proximity of small groups of people for team-based projects and adjacency of certain groups to specific core infrastructure / instrumentation may be valued, the co-location of research groups will not be guaranteed. It should be possible to use dynamic signage to demarcate space and showcase activity by project, program or portfolio to visitors/reviewers etc, rather than depend on geographical location within a building to do this.
Support services should be shared – By support services we mean the technical and professional personnel that support and enable the research enterprise. This includes technical and experimental officers, lab managers and attendants, storekeepers, and on-site administrative staff.
Research labs and equipment, where possible, should be shared – From the principle of shared support personnel it follows that equipment, supplies, and instruments can be

shared to a greater extent than the current dispersal of research across several buildings allows. This might take the form of zones configured so that similar types of equipment can be co-located and shared. E.g. a laser zone, a radio- active zone, a microscope zone, workshop zone, etc. Shared does not preclude access charges and in fact many labs depend on such income. Shared does not presume open access and where necessary boundary controls through specialized training and induction may be necessary.

These points extracted from the Space Manifesto for E3RI speak to support for a certain type of organisation: one that moves away from traditional lines of occupation of space and towards working in a way that really crosses boundaries. It speaks to *a blend of the archetypes* introduced at the outset of this section- somewhere more between research home and research hotel. The exact blend will depend on how we can sustainably fund the operation of E3RI.

Towards Funding E3RI

As stated at the outset, E3RI research and operation costs need to be funded in a sustainable way. The next step for E3RI is about setting out a detailed plan to tackle this. This will require us to fully flesh out costs involved and to

1. Create a plan for targeting big ticket and individual competitive funding opportunities at national and international level
2. Explore options for securing yearly guaranteed Government funding, similar to that given to the Tyndall National Institute
3. Identify and assess all external revenue sources ranging from access charges to facilities, rental streams from those co-locating, income from specific activities in the building, income from GCID related activity etc.
4. Identify and assess all internal funding opportunities ranging from overhead to school contributions
5. Explore options for partnerships with industry including membership models or IP access models
6. Work with TDA to further philanthropic engagement

The focus of E3RI, its location at the heart of the GCID, and the partnerships it can and will build, open up many new opportunities.

Conclusion

We opened this document by stating that as a university we have a responsibility to help solve the most challenging issues of our time. It is our belief that E3RI is a powerful way to do this. As we state E3RI is about the next stage in the industrial revolution, an *industrial, technological, ethical and ecological revolution* that will find the balance that we are looking for between the natural world, the digital, the human, a thriving society, and a thriving economy.

E3RIs is based on a foundation of research excellence, will bring a unique challenge-based approach and balanced solution philosophy to bear, and will be about building exceptional levels of partnership with industry, academia and civil society. E3RI offers a real opportunity to tackle challenges at scale that matters to people in Trinity and the world. E3RI will deliver world class research facilities, to allow existing staff to fulfil their potential, to attract new talent, to allow us to compete for funding that we otherwise would not be able to, to continue to enhance research informed teaching, to provide opportunities for students, to build stronger relationships with industry, to engage with the community, and to tackle challenges at scale that matters to people in Trinity and the world.

To a certain extent E3RI has already begun. The coming together of researchers across the disciplines to discuss ideas, work on the research vision, and think through the space manifesto has already broken down silos and opened up new dialogues and new ways of thinking.