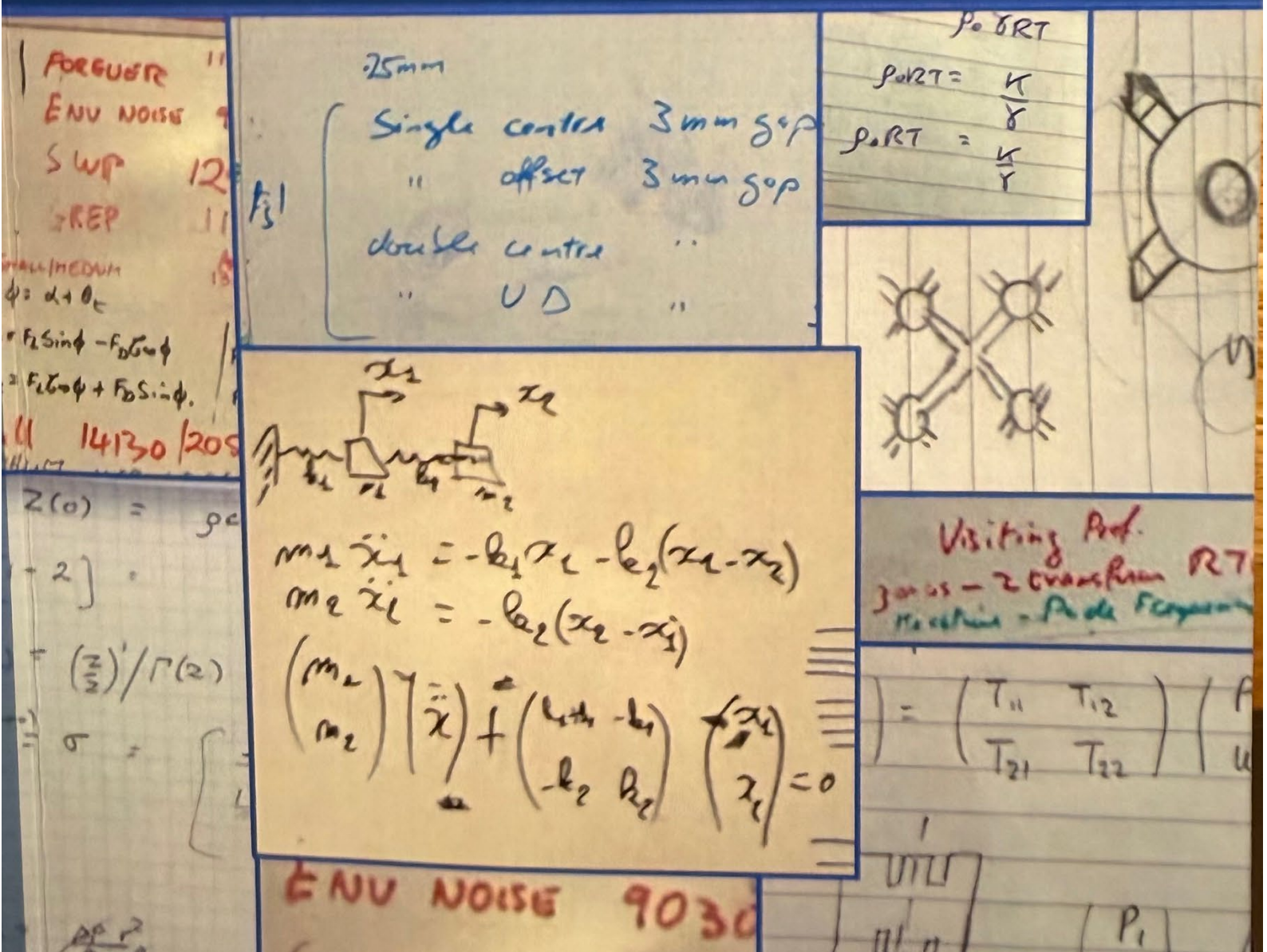
PERSPECTIVES ON ENGINEERING MECHANICS AND DYNAMICS

Essays in honour of Henry Rice

Editors: Ciaran K. Simms & Garret E. O'Donnell



Ears, Environments, Ethics

Patrick Prendergast

Trinity College Dublin

ABSTRACT

Some aspects of mechanical engineering from the early 1980s to the mid 2020s are discussed. I begin by recalling my first meeting with Professor (then Dr) Henry Rice, and I describe some research we later did on the biomechanics of hearing. I also discuss work on E3, a strategic initiative to grow teaching and research activities in engineering and other STEM disciplines. E3 was in the planning for a long time. The final approval by the Trinity Board came in April 2018. Construction of the E3 Learning Foundry eventually commenced during Professor Rice's time as Head of the School of Engineering (2016 – 2022). E3 stands for Engineering, Environment, and Emerging Technologies and I conclude by addressing a fourth E – Ethics. If engineering asks the question 'what can we do?' ethics asks 'what ought we do?'. Ethics provides a systematic way to think about the goal of E3 which has been described as 'Balanced solutions for a better world'. [1]

1. INTRODUCTION

It was spring 1986. Printouts of the proposed final-year projects were stapled onto the noticeboard in the foyer of the Parsons Building. About fifty projects were listed, each with a brief description of the work to be done and the name of the lecturer who would supervise it. To secure a project the students, of which I was one, had to get the lecturer's signature on a form we had been given earlier in the day. After reading the list we scattered to the different parts of the building to find the supervisor of our desired project. Some lecturers worked on a first-come-first-served basis – so speed was essential. Queues formed outside some lecturers' doors; sometimes there was pushing and shoving.

In those bygone days there was a lecturer's office on the landing outside the Mechanics Lab. In 1986 the occupant of that office was

one 'Dr H.J. Rice'. He had recently arrived from UCD, bringing with him a formidable reputation for his PhD work on dynamics of machines. I knocked on his door and announced myself; I wanted to be considered, please, for the project on 'Non-linear vibration isolation'. He told me it was not an easy project. It involved mathematical modelling and the design of an experimental rig. Was I sure? I said I was sure. He signed my form.

In the evening the students reconvened in the Lincoln. We traded stories of who-got-what-and-how. Mine was considered a brave choice. Earlier in the term Dr Rice had taken over the teaching of our 'System Dynamics' course. He worked out the solution to a problem of robotic control on the blackboard, without referring to any notes. He seemed to be testing himself. He took the whole hour, and some. In the end he pronounced himself satisfied with the solution. We were impressed.

This was my first meeting with the subject of this festschrift. The Department of Mechanical and Manufacturing Engineering had been founded only a few years earlier and it was still undergoing significant growth and change. There were discussions ongoing about the allocation of laboratory space. And there were differences of opinion about the importance of research relative to teaching. John Fitzpatrick gives an account of those turbulent times [2].

2. VIBRO-ACOUSTICS AND THE EAR

All animals live in a fluid. Most animals – insects, fishes, humans – communicate by sending vibro-acoustic signals to other animals in the fluid. Some species have organs to sense the fluid's vibration – organs we call ears. Mammals have ears with the eardrum (tympanic membrane) connected to the inner ear by three middle-ear bones: the malleus, incus, and stapes. This is as true for mammals living in a gas (e.g., humans) as it is for mammals living in a liquid (e.g., whales). A middle-ear with three middle-ear bones is, in fact, a defining characteristic of the class *Mammalia.*

Hearing became of interest in Mechanical Engineering in the early 1990s when we were approached by an ENT surgeon, Mr. A.W. Blayney of the Mater Hospital. He had done research work in Cardiff University with Dr Keith Williams and wished to begin similar collaborations in Dublin. Some early results were published by Blayney et al [3] with research done by a student under Henry Rice's supervision [4]. Later a finite element model of the tympanic membrane and middle-ear was used to determine the forced-frequency response of the ossicular chain [5,6]. **Figure 1**. We

analysed surgical repair of the ossicular chain with 'Partial Ossicular Replacement Prostheses (PORPs)' and 'Total Ossicular Replacement Prostheses (TORPs)'. These finite element models showed that the prostheses could reproduce the amplitude/frequency response of the healthy ear, except at low frequencies [7,8].

The finding that the prostheses could not reproduce the vibro-acoustic response at low frequencies led to further consideration of the purpose of the middle-ear bones themselves. Von Helmholz proposed that the three bones acted as a lever to magnify the force transmitted from the tympanic membrane to the inner ear [9], estimating the leverage to be approximately 1.4, see **Figure 2**. The idea became accepted that a frequency-dependent leverage was part of the middle-ear response for matching of the vibroacoustic waves in air to the fluid of the inner ear. However, a gain of 1.4 seems hardly to be worth the evolutionary effort [10]. Maybe there is a better explanation?

Consider that the ossicles are not just a lever but instead constitute a spring to magnify the force transmission at low frequencies. Other than by evolution of a soft-tissue connection, the only way to obtain this low stiffness is for the ossicles to evolve into a mechanical spring. Referring to **Figure 2** from Mason [9], the axis along the malleus/incus joint and the lengths of the lever arms, could act as a kind of flexible connection or a spring.

Why would mammals, and only mammals, evolve this mechanism? When mammals first appeared in evolution they were small shrew-like creatures. These mammals survived only if they could evade their larger reptilian predators whose approach was a footfall, a low frequency thud! To hear such thuds mammals needed to hear very low frequencies. Other animals, birds for example, have only one bone connecting the tympanic membrane directly to the inner ear and they hear high frequencies – chirps!

Research studying the design of several different designs of ossicular reconstruction prostheses [8] was an example of the kind of collaboration that later led to a successful bid to the Higher Education Authority to establish the Trinity Centre for Bioengineering (TCBE) and the development of Biomedical Engineering as a degree programme in the university [11].

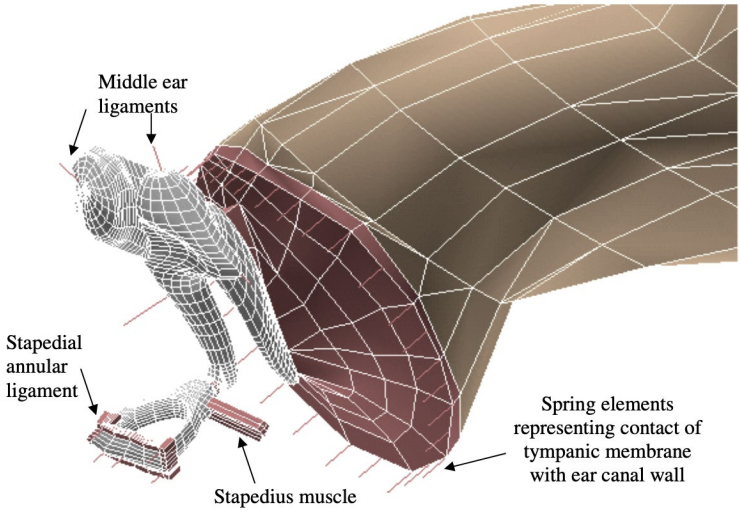


Figure 1. A FEM of the outer and middle-ear. MRI scanning was used to generate ear canal geometry [4,5]. MicroCT scanning was used for ossicles geometries, and ligaments and muscles were included as link elements in the tympanic cavity. From Kelly et al. *Bulletin Otorhinolaryngology Head and Neck Surgery* **7, 64-66, 2003**

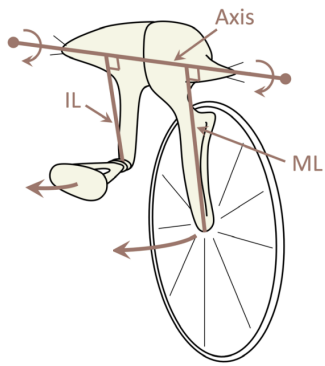


Figure 2. The force at the tympanic membrane is increased by the ratio of the malleus lever arm *ML* to the incus lever arm *IL*, from Mason, *Physio. News* pp. 16-19, 2022. According to the hypothesis of the lever ratio the linkage magnifies the force. An alternative view, however, is to consider the linkage to be torsion-bar spring.

Further growth the School of Engineering had been planned since the departments had been joined in the academic restructuring under Provost Hegarty. Up to then the Department of Computer Science had also formed part of engineering but during the restructuring they had joined with Statistics to form the School of Computer Science and Statistics.

The School of Engineering was operating from eleven sites throughout the college: 15-16 Westland Row, 183-193 Pearse St., Áras an Phiarsaigh, the Civil Engineering Laboratories, the Museum Building, the Parsons Building, the Printing House, the Simon Perry Building, the Sami Nasr Institute for Advanced Material Science (SNIAMS), the Trinity Biomedical Sciences Institute (TBSI), and the Watts Building [12]. Often these were very old buildings that had been re-purposed, for example the Printing House (built in 1736) or the Parsons Building (built in 1895). The dispersed nature of the School reflected the rapid response of Trinity to the educational needs of a growing population in the decades leading up to the Celtic Tiger. Great energy was brought to new School of Engineering by its first head, Professor John Fitzpatrick.

In this period, mechanical engineering was undergoing a change of emphasis in the curriculum to bring the subject of engineering design more to the fore [2]. This approach was, and is, resource intensive in terms of workshop and laboratory space, and it brought with it the need for new kinds of workshop and maker spaces [13]. New courses were also launched in Bioengineering [11] and Manufacturing with Management [14] putting further pressure on resources.

There was an increase in the importance of engineering and tech in the Irish economy and Trinity planned to respond to this by increased numbers of places at undergraduate and postgraduate level. The question was how we do it in a strategic way that meets the current needs of industry while enabling researchers to address the significant global challenges that were on the horizon.

3.1 Concept development

The proposal for E3 was developed during the 2010s. It aimed to bring the Schools Engineering, Natural Sciences, and Computer Science and Statistics together. It envisaged a phase 1 as a Learning Foundry built on the main campus and phase 2 as a Research Institute built at Trinity East. The collaborations between Schools would extend across both teaching and research and be highly interdisciplinary.

In the time Henry Rice served on the Board (2010 – 2014) the E3 concept was discussed first in June 2012 where the two Schools were to undergo a review 'by an international panel of experts' [15]. In the academic year 2013-2014 there was a series of Provost's Reports [15]: in September 2013 it was noted that there 'has been significant contribution from academic staff in the School of Engineering and the School of Natural Sciences in developing the E3 strategy'; in October the minutes record that 'the E3 strategy was broadened to be a college-wide strategy'; and in November that 'an E3 Planning Committee had been established'. By March 2014 an 'E3 strategy was being finalised and implemented', at the April Board meeting it was reported that 'E3 is a key infrastructural development for the university', and in June 2014 it was reported that 'a dedicated member of the fundraising team assigned to work full-time on it' [15]. As a Fellows' representative on the Board Henry Rice kept up the pressure to develop E3. This culminated in a commitment in the university's Strategic Plan (2014 – 2019) to 'Design and build a landmark new structure to house engineering and natural sciences in E3' and also that 'E3 will advance research in areas that address Ireland's economic priorities, leading to growth, competitiveness and job creation.' [16] This was a major public commitment by the university to expand engineering.

In the time Henry Rice served as Head of School (2016 – 2022) the E3 project moved into execution. A fundraising brochure published in 2016 articulated E3's ambition to 'Innovate for a Healthy Planet' positioning Trinity to meet the challenges of the future. Among the themes were 'The importance of an integrated approach to a low carbon economy', 'Sustaining and enhancing natural resources', and 'Creating technologies and solutions for a healthy society'.

Figure 3. The cover of the fundraising brochure produced for E3 in 2016. At that time E3 stood for Engineering, Energy and the Environment. Later this was changed to reflect better the involvement of the School of Computer Science and Statistics.

Also central to the E3 fundraising strategy was financing an increase in the number of student places from approximately 3,000 to 4, 800 (~60%) in the relevant disciplines of engineering, computer science, and natural sciences; this was to meet both student demand for places to study these subjects in Trinity and the demand 'for a new kind of graduate' in the multi-national and entrepreneurial sectors. E3 became a pillar of the college's 'Inspiring Generations' campaign [17]. In May 2018 Trinity announced a very significant donation from Martin Naughton to support the E3 Learning Foundry [18]. Throughout this period the Heads of School of Engineering, Natural Sciences, and Computer Science and Statistics met with the Faculty Dean as Project Sponsor to develop the funding model and advance the other elements. Several groups met simultaneously: viz, an E3 research strategy group and an E3 education and pedagogy group all reporting into the steering committee that, in turn, reported to the Board.

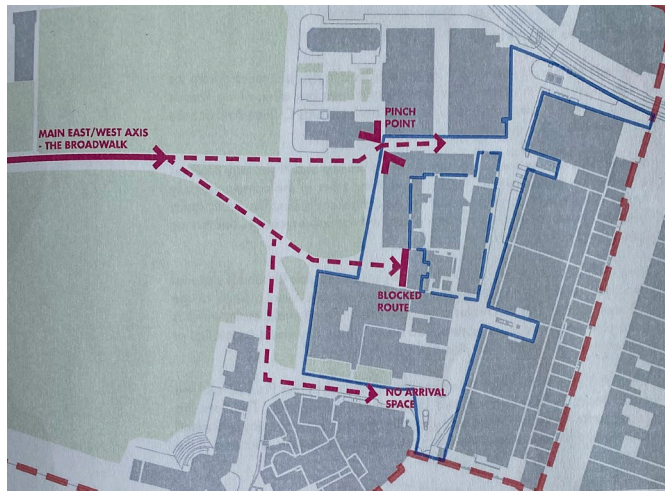
3.2 Learning Foundry

"We shape our buildings; thereafter they shape us"[1]

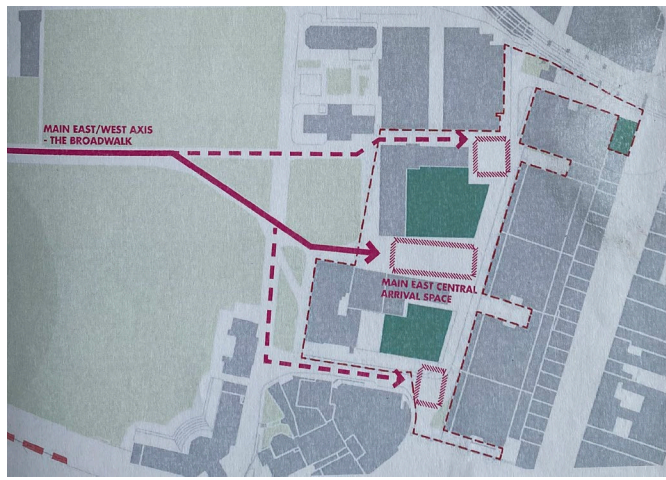
Simultaneously with the work being done to develop the academic and research programme, the Bursar Professor Veronica Campbell led the design specification for the E3 Learning Foundry with architects Feilden Clegg Bradley Studios. The design of E3 Learning Foundry was key for enabling the proposed changes in teaching and research and in this Henry Rice was an activist alongside his fellow Heads of School. Many options for siting the new E3 buildings were considered [19], including sites off-campus such as 1 Cumberland Place formerly the offices of Telecom Éireann and now the headquarters of X (formerly Twitter). We were out-bid for that site. Eventually a site on the east side of the campus was established. Clearing the site involved demolition of the Biochemistry building (constructed in the 1960s) and the 'Anatomy Annex' which had functioned at one time as an entrance to the School of Anatomy (constructed 1889/91). This small two-story annex was described as sitting 'uncomfortably between the main Anatomy building and the Zoology and Physiology building' [20], and its removal as part of the E3 development allowed for a new pedestrian route in the college. It should 'stitch the east side back up to the greater campus delivering a coherent whole' [21]. The Anatomy dissection room with its unusual artworks by Cecil Erskine, the classical Anatomy theatre, and the museum, were all retained with a potential future purpose relating to the medical school collections. The resulting site allowed the college to build a 7,256 m^2 building. The building was to be a 'living lab.', with innovative construction incorporating hybrid ventilation, energy and water metering observable by building users, and roof gardens used for teaching plant sciences. In addition, the redesign of the surrounding pedestrian spaces aimed to create a civic square and new connectivity along the west/east axis of the campus which may ultimately 'trigger a shift in the campus order', see **Figure 4**.

With the financial model complete, including predictions of student recruitment and staffing, a definitive business case could be presented to the College committees. Together with the design specification for the building and the cost estimates the proposal was accepted by the Board of the College in April 2018 [22].

[1] Attributed to W. Churchill



(a) before E3



(b) after E3

Figure 4. (a) Before the E3 Learning Foundry there were narrow, inconvenient west-east pedestrian routes; (b) After the E3 Learning Foundry there is a central west-east route and new civic squares. The aim of the squares is to encourage interdisciplinary encounters of staff and students. Note: the lower green block was not built as part of the E3 Learning Foundry Development.

3.3 Environmental Ethics

In a recent popular science fiction novel [23], an eco-warrior threatens to kill the Director of a Ministry responsible for future generations. The assassin says that the planet is burning and the Director is doing nothing. He points his gun at her –

"We're doing all we can", she says.

"No you are not, you're not doing all you can", is the reply.

Are we doing all we can for sustainability? Or all we ought to do? What are our human responsibilities to the natural world? How do we balance the needs of animals and plants with our own human needs? There are many ethical theories that can help us with such questions. For example, consequentialist ethics would ask us to consider the consequences of our actions for the natural world or virtue ethics which would ask us what our actions say about us and our character. Would you refrain from polluting a river because of the fish it might kill, or would you refrain because being a polluter is not the kind of person you are or want to be?

Sustainable development is central to E3. A definition of sustainable development is that it 'meets the needs of the present without compromising the ability of future generations to meet their own needs'. This long-standing definition accommodates the perceived need for continued economic growth while applying the constraint that such growth should not compromise the lives of future people.

There are several phenomena that are compromising the future liveability of the planet, foremost among them is climate change. CO_2 accumulation in the atmosphere is causing global heating compromising the planet for future generations. It shows us how urgent it is to act. However, it is proving difficult, if not actually impossible, for individuals, corporations, or nations to act to reduce CO_2 emissions. Even among individuals and groups who agree with the scientific consensus about the cause, there are very different views on how climate change should be addressed. Opinions cover the complete spectrum, from: (i) carry on as normal – we have no responsibility to future generations who can sort out their own problems; or (ii) have faith in engineers to develop technical solutions – human ingenuity has saved us before and will do so again, or (iii) immediately enter crisis management mode – introduce regulations and laws to curb CO_2 emissions in rich countries. However, somehow, there is a gridlock.

For Ireland, there is the additional argument that we are a small country and so our contribution to global CO_2 is minimal (0.1%)

and any reduction we would make would be swamped by the continued emissions of others. This fact suggests to many that any reduction in our CO_2-producing activities should only be done in a coordinated response with others on a global scale; without this global coordination some people say that it's not rational for any small country to jeopardize its own economic growth by reductions in CO_2 emissions. These reductions would be all the more pointless, so the argument goes, because the economic activity foregone by us would be rapidly taken up by others. Of course, we might reduce CO_2 emissions to 'take a lead' so as others might follow; or because it is the right thing to do, it is the morally correct action, it is virtuous to hold back because we feel some responsibility for the natural world.

We might have concern for the environment also because there are economic consequences of depleting our resources. When the E3 initiative started we fundraised using the argument that natural resources and ecosystems ('Natural Capital') and economic activity are linked. Consider that the natural world provides resources and services that are used to create economic activity which, in turn, leads to production and consumption of goods and services which can either add to or deplete that Natural Capital, as described in **Figure 5**. If our natural capital is depleted eventually the system will grind to a halt because nature will no longer be able to supply the required natural resources and ecosystem services. This idea was one of the conceptual tools used to link engineering and natural sciences in the context of the E3 initiative. It was stated that 'The philosophy behind E3 is that human activity can create a virtuous circle between technology and the natural world. Research and innovation must create technologies that sustain the earth's natural capital for future generations' [24].

Certainly the concept described in **Figure 5** is useful. But if we look at it through the lens of environmental ethics it is less convincing because it promotes the idea of nature having value in return for what it can deliver for human beings – this is anthropocentrism giving preference to human interests above all others as if animals and plants had been created only for our human use. Alternatively, we might consider, as most environmental ethicists would, that all forms of life have moral considerability – or some degree of moral standing which should be recognized. Most people

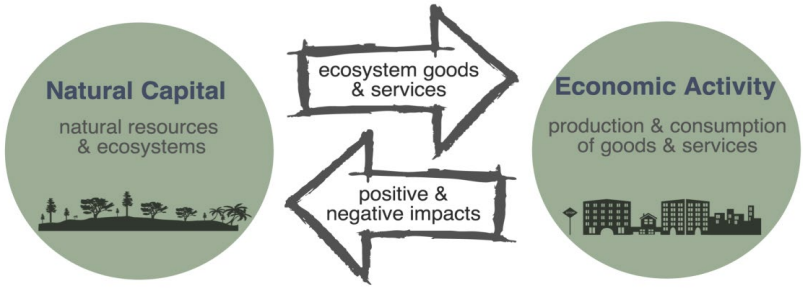


Figure 5. If we extract too much from nature or cause environmental damage we degrade our natural capital and put our economy at risk, from www.sustainableprosperity.ca

would agree that animals, wild animals in particular, have a life of their own that should be respected, that they should not be made to suffer unduly (or indeed at all) at the hands of human beings. A version of this (sentientism) gives sentient animals a higher degree of moral considerability than others. We might extend moral standing to plants as well and this is termed biocentrism. If we extend again to whole ecosystems of animals, plants and inanimate objects it is termed ecocentrism [25]. A great amount of thought has been given to these issues over recent decades [26], and while we may not yet go all the way to ecocentrism it is, I think, clear that we should, at the very least, question an instrumental a view of nature as, perhaps, a view that engineers have been prone to in the past. Technological solutions are often promoted whereas social solutions may be the ones required.

4. MÍLE BUÍOCHAS

Mechanical engineering in Trinity College Dublin has developed at a fast rate in the last 30 years. The pace of change has increased throughout the world but, given the situation that pertained in Ireland pre-1990, the change here has been more rapid than elsewhere because there was more ground to make up. It has required departments and schools to embrace new developments on a continuous basis and led to the Heads of Department and Heads of School engaging in university-wide strategic planning with a collaborative approach. It is a pleasure for me to add my voice to those thanking Professor Henry Rice for his singular contribution. In so doing we also recall to our minds the many colleagues who have played their

part in this success story over the years including several who are no longer with us.

It's not often one gets the opportunity to finish a paper with a poem, and I feel the need for it here! Recalling that Henry came to Trinity from UCD, and that much of this paper has been about hearing (soundscapes that resonate) and nature, who better to quote than Gerard Manley Hopkins in his paean for the environment:

> "What would the world be, once bereft
> Of wet and wildness? Let them be left,
> O let them be left, wildness and wet,
> Long live the wild and the wilderness yet"

I wish Henry all the very best for a long and happy retirement.

5. REFERENCES

[1] www.tcd.ie/e3 (last accessed 29/9/2025)

[2] J.A. Fitzpatrick, The life and times of C.G. Lyons: A somewhat personal view, in *Perspectives on Design and Bioengineering. Essays in Honour of C.G. Lyons*, TCBE, Dublin, pp. 11-17, 2008

[3] A.W. Blayney, K.R. Williams, H.J. Rice, A dynamic and harmonic damped finite element model of a stapedodotomy, *Acta Otol.* 117, 269-273, 1997

[4] G.J. McAvoy, *The development of a vibro-acoustic model of the human ear*, MSc Thesis, University of Dublin, 1995

[5] P. Ferris, *Finite element analysis of the normal and surgically reconstructed human middle-ear*, MSc Thesis, University of Dublin, 1998

[6] P.J. Prendergast, P. Ferris, H.J. Rice, A.W. Blayney, Vibro-acoustic modelling of the outer and middle-ear using the finite element method. *Audiology & Neuro-otol,* 4, 185-191, 1999

[7] D.J. Kelly, *A study of middle-ear biomechanics using the finite element method*, MSc Thesis, University of Dublin, 2001

[8] D.J. Kelly, P.J. Prendergast, AW Blayney, The effect of prosthesis design on vibration of the reconstructed ossicular chain, *Otology and Neurotology* 24, 11-19, 2003

[9] M.J. Mason, Marvellous middle-ears, *Physio. News* 16-19, 2022

[10] P.J. Prendergast, Mechanics applied to skeletal ontogeny and phylogeny. *Meccanica,* Special issue from the Symposium on Biomechanics of Italian Association of Theoretical and Applied Mechanics, 26-29 September 2001, Taormina, Sicily, 37, 317-334, 2002

[11] D.J. Kelly, F.J. O'Brien, P.J. Prendergast, A short history of Bioengineering research in Ireland. *ASME J Biomech Engng*, 140(2), Article 021005, 2018
[12] Turnberry Consulting, *Trinity College Dublin E3 Project Update*, Executive Officer Papers, Trinity College, July 2016
[13] G.J. Bennett, G. Lyons, K. Kelly, Implementation of a CDIO compliant syllabus in a large engineering programme, in *25th International Manufacturing Conference*, Dublin Institute of Technology, Dublin, Robert Simpson (ed.), pp. 314-322, 2008
[14] K. Kelly MEMS – Making engineering with management a success, in *Perspectives on Manufacturing. Essays in Honour of John Monaghan*, TCBE, Dublin, pp. 45-56, 2015
[15] Board minutes, BD/11-12/291, BD/13-14/010, BD 13-14/045, BD 13-14/071, BD/13-14/241, BD/13-14/292
[16] Trinity College Dublin, *Strategic Plan 2014-2019*, p. 58, 2014
[17] Trinity College Dublin, *Inspiring Generations*, www.tara.tcd.ie
[18] *Irish Times*, Trinity College Dublin announces €60m campus development. 2018 (25 May)
[19] *University Times*, College considering off-campus location for E3 Institute, 2016 (18 March)
[20] Paul Arnold Architects, *Proposed E3 Development at Trinity College East. Conservation Issues and Initial Considerations*. 2014 (14 May)
[21] Feilden Clegg Bradley Studios with Arup, Coady Architects, Grant Associates, MacCabe Durney Barnes, Allegro Acoustics, *Trinity College Dublin E3 Learning Foundry, Balanced Solutions for a Better World, Anatomy Design Note*, 2018 (23 September) and *Landscape Presentation*, 2020 (30 January); Arup, *E3 Foundry Sustainability Design*, 2019 (15 February)
[22] V. Campbell, V. Cahill, P. Coote, E. Hegarty, *E3 Phase 1 Business Case*, Trinity College Dublin Board Papers, 2018 (25 April)
[23] K. Stanley Robinson, *The Ministry for the Future*, Orbit Books, 2020
[24] P.J. Prendergast, *E3 Discussion Paper at Executive Officers Group*, 2015
[25] R. Attfield, *Environmental Ethics. A Very Short Introduction*, Oxford University Press, 2018
[26] S.M. Gardner, A. Thompson (Eds.), *The Oxford Handbook of Environmental Ethics*, Oxford University Press, 2017