CULTIVATING THE O-SHAPED ENGINEER

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Abstract: Within their roots in the realm of construction, products and the physical world, it is not surprising that design and engineering education is grounded within the paradigm of consumerism and growth, perpetuating an unsustainable system. Often, the primary sustainability focus is on material improvements aided by the use of tools such as life-cycle assessment or embodied energy calculations. Students are rarely asked to question the context into which their designs will fit, or to explore how their designs can promote a different (more sustainable) future rather than just a less unsustainable one. While we remain within this economic paradigm, even the T-shaped engineer, with a broad general knowledge and deep expertise in one specific area, at best has potential to reduce negative environmental impact rather than to create positive social and environmental benefit. As such, the T-shaped engineer is allowed little opportunity to creatively explore more sustainable alternatives using systems-level thinking.

How, then, can we prepare the next generation of designers and engineers to maximise their inherent skills to address the most intractable global issues, currently considered outside of their traditional remit? This paper questions if T really is the best shape for our engineers to adopt, or if it supports the designing of a better future world, proposing instead the O-shaped designer/engineer, whose primary concern is circular systems, worldviews, synergies and relationships. By training students to identify their personal values, redefine the brief and continually evaluate the balance between the social, environmental and economic impacts of their design, we can begin to intervene in the context of any given project, and create viable new ways of doing everyday things.

SustainRCA at the Royal College of Art is exploring tools and methods to cultivate and support O-Shaped, rather than T-shaped, designers and engineers. One such tool, the Circular Thinking Workflow System, tracks, monitors and evaluates individual and group work through four key stages that help them examine the brief at different distances of focus – from the systemic 'zoomed out' view to the people-focused 'zoomed in' view – as well as the flows and relationships between them. There is also a strong emphasis on economic context, encouraging students to develop innovative ideas that can function in the real world, thus favouring the creation and development of viable entrepreneurial thinking. Conventional sustainability tools may still play an important role in reducing impact of physical objects; but if these objects are now instruments for the functioning of a new context or system, radical sustainable innovation becomes possible. Similar methodology is used in the development of action research work, where diverse issues – from sustainable mobility to high-welfare/low impact poultry farming - can be addressed, both from a user's perspective and at a systems level.

This paper will examine some of the tools used in depth, explaining some unexpected but essential components. Through two case studies it will show how their application is generating sustainable innovation and delivering new O-Shaped calibre of design engineers, ready to rebuild the future.

1 THE O-SHAPED

Outgrown. Has the Design & Engineering (D&E) world outgrown the letter T, coined by David Guest (Guest, D. 1991) and adopted by Tim Brown as the need for individuals with both broad knowledge and specific skills? Made up of a horizontal line intersected at right angles by a vertical line at its mid-point, the T is purely linear. As such it has worked very well as a representation of the skills best suited to a linear world model. But if our linear model is no longer fit for purpose, do we need to update the letter T?

Order and law. Design has long been a tool for our linear growth model, helping drive the 'hedonic treadmill' (Porritt, J. 2008) of the growth economy. Furthermore, the impact of design and engineering on the environment has been well documented. The German Federal environment Agency reported in 2000 that 'more than 80 per cent of all product-related environmental impacts are determined by product design', and the UK's sustainable development strategy from 2007 declared that 'we need a major shift to deliver new products and services with lower environmental impacts'. All over the world, new laws and standards (eg ISO 14001[i], WEEE Directive[ii] and RoHS Directive[iii] in EU) are aimed at stimulating the redesign of products to reduce environmental impact. It is compliance with this legislation that seems to have largely driven response from D&E education, leading to the development of a host of tools and methods for reducing unsustainability (Lilley, D et al 2005). This paper suggests, however, that although the design world is to some extent already addressing sustainability, the T-shape and what it represents is no longer fit for purpose. T may help increase efficiencies and reduce environmental impact, but as explained by the formula I=PxAxT (Ehrlich et al, 1972), overall increases in population combined with an increased ability to buy ever cheaper goods means that these efforts can never be impactful without changing the system within which they exist. A brief analysis of the context into which our graduates will emerge at the end of their educational experience is needed.

Our impact. As predicted in 1972 by Donella Meadows and the Club of Rome (Meadows et al., 1972), our environmental capacity to provide for the needs of humans on the planet has reached its limits. World population, which has now surpassed 7 billion, continues to grow. OECD Development Centre reports that vast numbers of people in the developing world, particularly Asia, are joining the ranks of the "global middle class" which is estimated to increase from 1.8 billion in 2009 to 3.2 billion by 2020 and 4.9 billion by 2030 (Karas, H. 2010). While the lifting of so many people out of poverty is to be applauded, it comes hand in hand with all the expectations of the associated lifestyle and has already lead to a surge in the sales of consumer products such as refrigerators, television sets, mobile phones, motors and automobiles. All have been designed.

Obliteration? The associated problems are multiple, complex and interconnected. In his book Collapse, Jared Diamond (Diamond, J. 2005) identifies five factors that have contributed to societal collapse in the past, all of which we are currently facing: climate change, hostile neighbors, collapse of essential trading partners, environmental problems, and failure to adapt to environmental issues. In October 2008, New Scientist magazine published a special report entitled: How our economy is killing the Earth (Marchant, J. 2008). The report offered a stark reminder of the crisis facing our planet. "Consumption of resources is rising rapidly, biodiversity is plummeting and just about every measure shows humans affecting Earth on a vast scale". An illustration (figure 1) tracking progress of some of our main contributors to environmental destruction from 1750 to 2000 starkly illustrates the steep upward trend of all of these indicators. These include deforestation, soil fertility, water management, overhunting/fishing, destruction of biodiversity, climate change, energy shortage and build of toxins in the environment.

One sided. In 2014, a study partly-sponsored by Nasa's Goddard Space Flight Center highlighted the prospect that global industrial civilisation could collapse in coming decades due to unsustainable resource exploitation and increasingly unequal wealth distribution (Motesharrei, S et al., 2014). In fact, according to a report by Oxfam the gap between rich and poor continues to grow, with 1% of the world's population now owning more wealth than the other 99% (Hardoon, D., 2015). The World Economic Forum's Global Risks 2014 report highlighted the risk to world stability of the widening gulf between the incomes of the richest and poorest citizens.

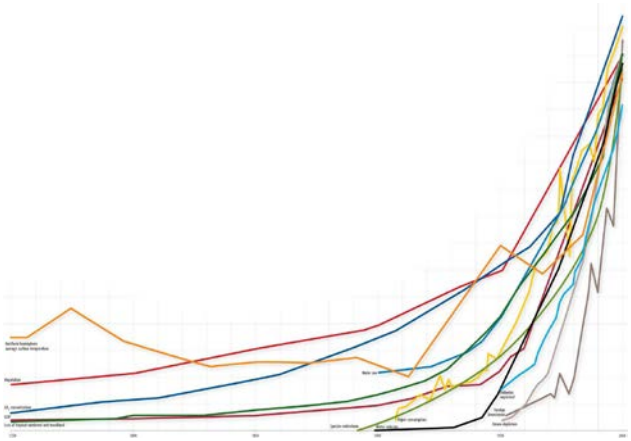

Fig 1: Increasing impact of industrial civilisation 1750 – 2000, (Springer-Verlag, Berlin, Heidelberg, New York)

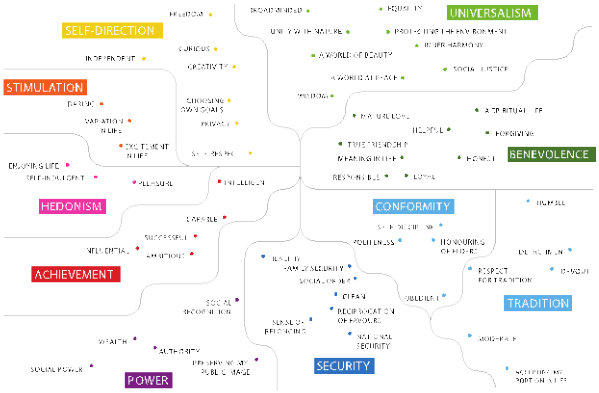

Fig 2: Map of Universal Values, Public Interest Research Centre

Outdated? This is not only an environmental and resource crisis but also a financial overload, a world in debt (Heinberg, R. 2007). Continued economic growth within our current linear system is an unsustainable and unattainable, with growing evidence of the inextricable link between the growth of the free market and climate change (Klein, N. 2014). Our linear economic model requires an ever-increasing repetition of the same 'take, make and dispose' process (Mckinsey/Ellen MacArthur Foundation, 2012), destructive at every step: we extract resources from the ground and cut down trees; we use fossil fuel-derived energy to process them into products, buildings and infrastructure; we consume them and dispose of them, mostly in the ground. Our resulting energy demand, largely derived from non-renewable sources, is pushing up our CO2 emissions and leading to dramatic changes in the earth's climate. At the same time, we are poisoning the earth's crust with toxic substances, many of which are of dwindling availability and could be of great value in the industrial world.

Over-indulgence. In spite of our addiction to the growth model, beyond a certain level of comfort and wealth (Jackson, T. 2009) our life satisfaction does not increase, and we may actually become less happy. 'We live in a world that is unfair, unhealthy, unstable, unsustainable, and it is making us unhappy' (Simms, A, 2014). The growth model no longer works either socially or economically (Heinberg, R. 2001), and, with the best will in the world, our T-shaped designers, reducing negative impacts, are not helping.

Out of date? This is the backdrop to our educational strategies, which have not developed appropriate responses. An ample selection of tools and methods to help designers lessen the overall impact of their design decisions and comply with environmental legislation such as specialised CAD software, Life Cycle Analysis, indexes of material toxicity, embodied energy calculators~~,~~ ~~a~~ddressing mainly materials, compliance, and physical things rather than infrastructure, systems, people and society. They may tick the compliance box, but they do not inherently help address issues such as working conditions, end of life disposal, manufacturing and use, repair, reflecting the inadequacy of T. We need to move beyond compliance with a linear system to creating Net Positive. We need big picture analysis and systems thinking; we need to redesign not only the stuff but also the relationships that bond society and our business models; we need to think in cycles and apply circular economy manufacturing loops using rigorous cradle-to-cradle thinking in everything we create. We need to learn to work with other disciplines, to be able to zoom out to explore meta-themes at global scale and zoom right back in to deeply understand users and their journeys through our new systems. We need to be able to map and visualise new world-views (fig. 3) and explain how new economic paradigms will work, and use the power of design to describe as yet unimagined, circular futures. We need to aim for O (Elkington, J, 2012).

O. An analysis of the letter O reveals a shape that has resonance at many levels: it is a shape that represents the needed worldview of earth itself; it is a closed loop, like the production systems we need to develop; it is geometrically symmetrical, with any point along its periphery being equidistant from the centre thus equally important; it has no beginning and no end, bringing an emphasis on a temporal dimension and the need to constantly renew and iterate; it is 3-dimensional and it's path is infinite (fig. 3)

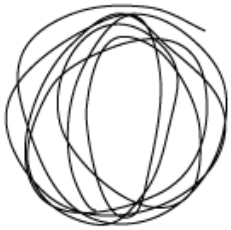

Fig.3: an attempt to visualise O-shaped

WHICH DESIGN TOOLS AND METHODS DO WE ALREADY HAVE FOR 'O'?

Designers are already well equipped to make the transition to O. Summarised below is a non-exhaustive list of appropriate existing and inherent skills and their value in the transition to O:

- **Research** has always been a core requirement for any design brief. Design responses that seek to solve a problem without first understanding the bigger picture risk simply shifting the problem from one place to another. O-shaped designers must start by thoroughly exploring each topic, to find out what is already happening, who is involved, and how the existing stocks and flows of people and resources work.
- **Mapping** enables a visual, zoomed-out view of research that can be easily shared with others, helping change worldviews and opinions of what is possible. It enables the deconstruction and reassembly of situations and stakeholders, the creation of new scenarios and new relationships between people, business and government (Sustainable Development Commission, 2006).
- **Human centred design** and co-creation requires a zooming in to uncover peoples' latent needs, understand what drives their current behaviour, and works with them to uncover successful solutions. This understanding expands our creative potential and supports a shift in the way people do everyday things on a long-term basis, helping avoid the creation of negative feedback loops, where efficiencies in one area may simply lead to excesses in another.
- **Testing and prototyping** allows ideas to be quickly and cheaply tried out to identify strong and weak points prior to production and up-scaling.
- **Drawing and visualisation** skills help to explain and communicate complex ideas and possible hard-to-imagine futures, communicating with diverse stakeholders in a common language.
- **Measuring and evaluation** Clearly we will always need products and infrastructure, so understanding their impact at every stage is critical.

WHAT KIND OF TOOLS AND METHODS MIGHT NEED TO BE DEVELOPED FOR 'O'?

- **Biocentric** thinking is currently not on the designers skill list. Not an alternative to human centred design, Biocentric is an additional consideration for design that enables the viewpoint from other perspectives such as animals, plants and the wider ecosystems in which they exist. Biocentric thinking allows us to address e.g. our food systems, where food animals are currently treated as part functional system, engineered for human practicality. By incorporating their experiences into the design process, the resulting design of the system would be very different.
- **Thinking in systems** is important in the research phase to get an understanding of which different systems are involved in any given situation, and how they may need to change or combine in new ways. Engineers are comfortable thinking at systems levels, while this is not part of a designer's traditional remit.
- **Goal focused and future-scoping** Designers and engineers are primed to provide solutions to existing problems. While this in itself is a useful skill, it is important to be goal focused rather than problem focused, aspiring to a sustainable future rather than tweaking the current system.
- **Asking the right questions.** Aided by good mapping and systems thinking, it is necessary for designers and engineers to challenge the brief, and for professors to reshape the questions asked.
- **Thinking in services** can help avoid the creation of physical things where the required outcome may be provided in their absence.

- **Business thinking** will be essential in order to make sure that ideas fit within a circular economy model
- **Working collaboratively** and with experts from other disciplines enables teams to address complexity
- **Measuring social impact** In a circular world, it is critical to measure social as well as economic and environmental impact. The many existing methods need to become part of the engineer's palette.

2 O-SHAPED CLIENTS

Until recently, one of the biggest challenges with training our students into a circular mind-set was how they would find employment for their skills in the real world: there is little point in proposing o-shaped projects to clients who are still working in a linear model. This is certainly still an important challenge, but one that, I would argue, is gradually shifting, largely due to the rise in interest in the circular economy. The Ellen MacArthur Foundation, for example, a UK organisation that is leading on circular economy thinking, is galvanising enthusiasm from companies around the world to seek alternative business models, a goal which it recognises cannot be achieved without connecting businesses with academia, particularly with design and engineering. An increasing number of businesses are recognising that business as usual is not an option for the future, and as a result recruitment opportunities are growing. According to a 2014 survey, demand for sustainability jobs in the US more than doubled between 2010 and 2014, (Lombardi, A, 2014) with engineering among the fields with the most demand. Furthermore, public interest in sustainability and demand for information and transparency is also growing. An internal research report by Ikea in 2013 identified an 85% increase in sustainability-related questions on their on-line blog, with 10% of all comments on the blog now being sustainability related (Ikea 2013). These factors are improving the jobs market for O-shaped designers, and are destined to continue to do so into the future, but for many O-shaped graduates who want to generate a net positive impact there will be an imperative to set up their own businesses whose aims are improving social and environmental wellbeing, and to engage with other similar players in the market in order to be a part of O-shaped supply chains. This will require our graduates to have some degree of literacy in business thinking.

3 TRYING NEW EDUCATIONAL STRATEGIES FOR A CHANGING WORLD

Royal College of Art (RCA) is a postgraduate university of art and design covering a wide range of disciplines from fine art to engineering through two-year Masters programmes. SustainRCA, an independent research centre at RCA, supports programmes through a series of activities to drive sustainability thinking across the college, including: cross-collaborative academic and client-facing research into world issues such as Circular Economy, Energy and Food; a Talks programme that inspires and informs students about exciting sustainability action and thinking; an annual exhibition showcasing the best of graduate thinking in sustainability; tutoring and teaching within programmes. Two case studies below explain how O is helping drive innovation across the College.

3.1 Case study 1, Innovation Design Engineering, a 2 year Masters Programme

IDE students come from a variety of backgrounds including science, engineering, design and business. The challenges set are very much of a systemic rather than product nature, making it an appropriate place to begin experimenting with the creation of O-shaped professionals. We have been testing and integrating new design approaches into the course, nurturing student interest in 2nd year self-generated briefs, ensuring that they ask the right question at the outset of their projects. 'Sustainability' became a core learning objective and exam criteria in 2008. A range of tools and methods, along with specialized tutoring, help students think in circles and cycles.

The Circular Thinking Workflow System (CTW) is a framework that embeds sustainability principles from the outset, and helps perceive sustainability as a stimulator of creative innovation rather than as a constraint. Projects follow a rigorous double-diamond style four-phase project process (Design Council, 2013), requiring specific outputs at each phase (see figure 4) that demonstrate a balance between three parameters:

Environmental asks students to think about the bigger picture, and consider the possible environmental

implications and applications of their work. Beyond materials and the environmental impact of their extraction, processing, use and disposal, they are asked to think about how they can fit within a circular economy model, including for example: cradle-to-cradle thinking (Braungart, M et al 2002); durability (Chapman, J, 2002); recyclability and impact of lifestyle / product use.

Social/ethical explores how design decisions might protect and enhance people, communities, behaviour and relationships. Does the project promote pro-environmental behaviour? How can sectors of society interact in new ways, for example businesses, local / central government, individual people / communities, third sector, or lead to better health and wellbeing? What are the labour implications of the project? Does the project impact on other sentient beings, rather than only humans?

Economic relates to the commercial sustainability of the idea, and to the application of circular economy thinking. A project must demonstrate the ability to theoretically survive and thrive in the real world, either through a new enterprise or existing commercial organisation, with evidence of a business model to establish and sustain it. They also may explore: Scalability; decoupling growth from environmental impact; patterns of consumption; wealth distribution; resource and energy costs; shifts in population, markets, pricing ecosystem services; resilience of local economies.

Phase 1 – Research and Drivers Students explore their personal values making their project relevant them individually as well as to broader to Social, Environmental and Economic contexts and issues. Based on a values map (figure 2) created by PIRC (Holmes, T. et al., 2011), they identify and connect their core values with the chosen theme for their project, looking at broad global issues from a 'zoomed-out' perspective. Deliverables are visual, helping identify the most appropriate direction for their project and may include: images, evidence of relevant trends and issues, facts or figures, examples of contexts and scenarios. Critically, students must stay away from developing solutions and focus simply on exploring the problem.

Phase 2 – Idea Generation and Brief Definition. Students explore the design opportunities inherent in an area of interest, zooming in to look at one issue in greater detail and beginning to define their brief. Systems are mapped to illustrate the project's social, environmental and economic themes, and to position existing and potential stakeholders. Short visual presentations include a statement of problems and opportunities in the three areas, culminating in a refined design brief.

Phase 3 - Develop/Assess. Students have identified the brief and are generating ideas and future scenarios. They develop a narrative, showing how their proposed system will be different from existing ones. They are encouraged to use personas to describe how their idea will affect people, and create user journeys to identify touch-points and possible service models. Their thinking must reflect current and forthcoming trends, legislation and standards, show the variables, and consider how they could be measured. Deliverables include visual and written explanation of relevance to wider context; an assessment of different approaches; possible use scenarios; visual resources to illustrate systems, models, impacts and benefits

Phase 4 - Deliver / measure – The CTW culminates in a report and a final sustainability exam, in which they must explain the impacts and implications of their idea, and show its value through a broad range of appropriate visual tools such as scenarios, prototypes and user tests, films, and systems mapping.

The four phases of the Circular Thinking Workflow help students:

- Take inspiration from researching contexts and build an evidence base
- Hold off on jumping directly to the design of solutions
- Use tools to analyse and spot opportunities for design interventions
- Generate and compare ideas for systems while understanding their benefits and impacts
- Explain the final proposal through a quantified pitch

Through the process, students are encouraged to pick from a palette of existing tools to assess and improve environmental impact of their design decisions. The process being developed within IDE does not set out to replace or improve on these tools, but rather aims to provide a holistic framework in which those tools each have a role to play in different phases of the design process.

Results from these combined methods have been encouraging, and we are seeing a growing number of enterprising and solution-based projects that address issues of global importance. The CTW is an iterative document, with feedback and input from students themselves helping to refine and develop the methods and supporting documentation, which is continuously updated. An insistence on the delivery of visual material has both strengthened the research base of the projects and generated some interesting

techniques for mapping and visualising complex information. There is insufficient space in this paper to explain in depth some of the results of the sustainability teaching, but examples include: an open-source bicycle-driven copper and PVC recovery tool for waste sites in (www.halwatts.co.uk/Esource); an innovative, environmentally friendly alternative to death and burial process and rituals (http://tinyurl.com/c4bo4pf) and an enrichment system to improve the welfare of pigs in industrial facilities (http://tinyurl.com/97z4o5z).

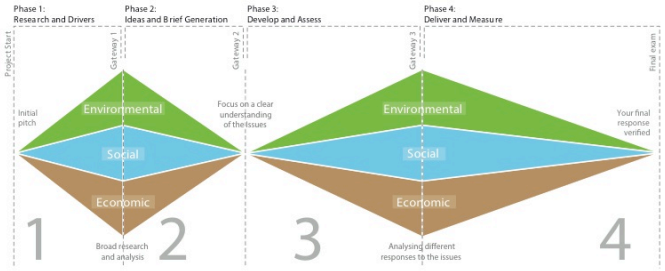

Figure 4. Circular Thinking Workflow diagram

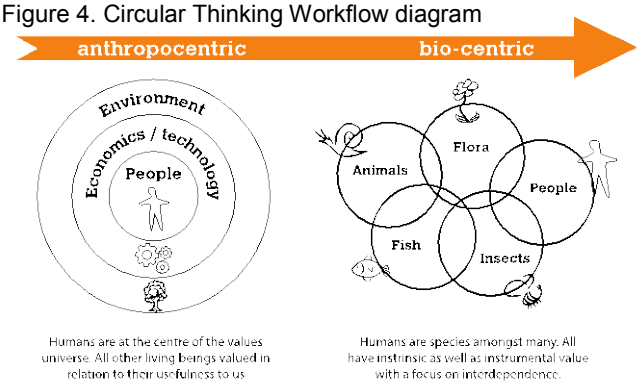

Figure 5: Anthropocentric to bio-centric, Rawles, K, 2010

3.2 Case study 2, SustainRCA, application of O-shaped teaching into multidisciplinary learning

The processes described above have been used in accelerated versions for action research projects with cross-disciplinary teams and commercial clients, leading to new and unexpected outcomes. For example, The Chicken Run Project used a bio-centric approach (figure 5, Rawles, K, 2010) that is beginning to emerge in mainstream media (Thorsen, Ø, 2015) to address the welfare issues inherent in the commercial production of poultry. The research phase involved visits to both commercial and best-practice farms, with exposure to in-depth information about the environmental and welfare impacts and issues of the entire production process, and opportunities to talk to all stakeholders. In development, narratives were created through the mapping of the chicken's journey, from egg to shop, seen from the perspective of the three main stakeholders: farmer, consumer and the chicken itself. Different sub-strands emerged, looking at issues regarding, for example, feed, air-flow in the barn, poultry enrichment and consumer education. Finished proposals were presented back to the client, leading to a number of proposals being currently taken forward at commercial scale. These included: a straw bale of varying density that enable poultry to engage in natural huddling, pecking, scratching and perching behaviour throughout the crop according to the age of the birds; a perch integrated into the feeding lines; a mat embedded with sprouting seeds providing distraction and nutrition in the shed; and an exploration into the potential of introducing black soldier fly larvae into the sheds as a source of enrichment and alternative feed source. In another cross-disciplinary project, student groups looked at the future of sustainable mobility by creating possible scenarios in 2025 and looking at users today who will be at driving age by that time. By projecting forwards, and then back-casting, a number of interesting sustainable business

opportunities emerged that led the focus away from the vehicle and towards different relationships in society to support more sustainable mobility.

4 CONCLUSION

We have passed the limits of our current linear economic model of consumer-driven material economic growth. New models of wellbeing are ready to be discovered and we must create O-shaped designers – preparing them for a new way of working - in order to do it, ready to go out and create entrepreneurial net-positive projects into a circular world, by putting a greater emphasis in the curriculum on systems, loops and circular economies, by encouraging focus on goals and outcomes, and by offering of specialised support modules, tools and teaching. Points of learning that are worth underlining include:

- Identify and connect with every individual's values
- Structure project work into distinct phases to allow a broad research phase before students start working on a solution
- Require students to explore issues through extensive visualisation and mapping
- Set circular goals and criteria from the outset of a project.
- Offer specialised tutorials throughout the process, and connect students to a wider network of specialists according to their needs

Unless we come out of a t-shaped mind set and start to adopt an O shaped one, considering context and asking the right questions, we will never be able to reach truly sustainable outcomes. We at the beginning of a journey to support this change, and are developing tools and methods to drive it forwards. It's time to move on from the letter T.

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Notes

[i] ISO 14001:2004 sets out the criteria for an environmental management system and can be certified to. It does not state requirements for environmental performance, but maps out a framework that a company or organization can follow to set up an effective environmental management system

[ii] The Waste Electrical and Electronic Equipment Directive (WEEE Directive) aims to reduce the amount of waste electrical and electronic equipment that ends up in landfill. Together with the RoHS Directive 2002/95/EC, it became European Law in February 2003.

[iii] The Restriction of Hazardous Substances Directive 2002/95/EC, (RoHS 1), restricts the use of certain hazardous substances in electrical and electronic equipment