Integrating Thermodynamics and Biology for Sustainable Product Lifecycle Design

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Introduction

The link between the consumption of natural resources and economic growth through product manufacture and disposal (cradle to grave) is creating an untenable pressure on the planet's ecosystems (Heinberg, 2007; Meadows, 2004; McDonough, 2002; Krugman, 2008; Stern, 2007; Stiglitz, 2010).

Furthermore, the index used by nations around the world use to measure economic growth is Gross Domestic Product (GDP); this is "the sum of all value added to raw materials by labour and capital at each stage of production, during a given year" (Daly and Farley, 2004). From this definition it can be inferred that the more efficient labour is, the less capital is needed and more added value can be achieved. This principle drives technological improvements, and underpins a continuous search for efficiency; which in turn creates another complex linkage with the balance of unemployment (Jackson, 2009). In order to keep people employed and avoid social collapse more products must be created.

This trend is well defined by Jevons' paradox (1865), where technological efficiency instead of easing pressure on the planet and people, creates more demand, consumption and dependency. The way we design, build and use products, and even keep social cohesion is based on a constant structural need for avoiding collapse, fed by positive feedback loops that only increase its negative impacts.

This model for economic growth ignores one crucial objective: bringing wellbeing to people. The strongest evidence of this is in the relationship of the Human Development Index and GDP per capita; figure 1 shows that after a certain level of income is achieved there is little to no impact on human development. This figure also clearly shows a more dense area in low-income countries and hence illustrates the unevenness of the macro economic system (HDR UNDP, 2011).

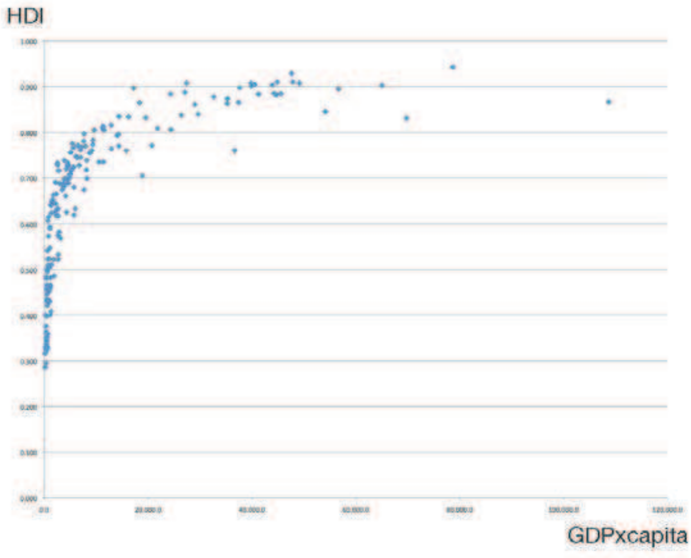

Figure 1 HDI vs GDP per capita

Previous research into macroeconomics frequently raises the question: what size the economy should be? If it is accepted that macroeconomics is not an isolated system but a subsystem dependant on the Earth's ecosystem services (Daly, 1991) it is physically impossible to sustain perennial growth within the current model (Georgescu-Roegen, 1999; Latouche, 2009; Daly and Farley, 2004; Meadows, 2004). With this idea present, size and distribution (GundInstitute, 2011) of businesses become key to achieve long term sustainability as well as to empower local development, biodiversity protection and thus a more equitable human development.

By taking this biophysical approach (TEEB, 2010) the direct relationship between economics and natural systems emerges through the laws of thermodynamics. In the natural world energy and matter are transferred and exchanged under very specific rules that have allowed living organisms long term sustainability for more than 3 billion years.

Numerous attempts have been made to value and measure ecosystems services and to assess the impact of human activity through thermodynamics. 3 possible calculation methods have been used: entropy (Kleidon, et al. 2010), emergy (Almeida, 2010; Odum, 1996 & 1998; Bastianoni, 2007; Brown, 1999; Jorgensen, 1995; Hau, 2004a; Ulgiati, 2009) and exergy (Sciubba, et al. 2008; Hua, 2004b; Bakshi, et al. 2011). All of these require highly specialised knowledge and data to inform large system analysis, this is complicated to obtain and very limited in it's scope.

The design field offers multiple initiatives to empower sustainability, for example: Okala Design Guide, Designers Accord, Natural Step, Total Beauty, Biomimicry, Natural Capilalism, Cradle to Cradle, Sustainability Helix, Sustainability Scorecards, Living Principles; there are many coincident points within different perspectives, but Shedroff (2009) summarises its very clearly: "One serious problem for designers is that, even with a systems approach, there are few tools in existence that wrap these issues together. Instead, designers must learn to match together a series of disparate approaches, understandings, and frameworks in order to build a complete solution".

Motivation

Designers are, by active association, responsible for the pressure on Earth's ecosystems and much of the impact can be traced back to the early stages of the design process. For designers and engineers the main constraint is accessibility to knowledge of multiple and complex factors in an easily digestible form even before starting a project. Added to this is the possibility to transcend the realm of products and explore creative solutions throughout the entire life cycle, giving designers the opportunity to propose entire new business models and systems.

Schwab (2012), questions whether capitalism is not being replaced by what he calls "talentism" as he states that: "capital is being superseded by creativity and the ability to innovate".

Question / problem

The principal goal in seeking long-term sustainability is decoupling which means “reducing the rate of use of resources per unit of economic activity” (UNEP, 2011; OCDE, 2002).

On the other hand there is the above-mentioned lack of integration of multiple and complex factors in today’s design practice. Interestingly Schumpeter (1954) states that every analysis starts with a preanalytic cognitive act he calls “vision”, whatever is not included in that preanalytic vision cannot be reckoned by ulterior analysis.

Therefore, such an integrating tool must be directed to allow the creation of the preanalytic vision, even before any analysis on the matter is performed. This concept is more easily explained in figure 2, the first section refers to Shedroff’s view, where multiple and complex factors “must be learned” by designers, leaving in this way sustainability solutions dependant on designer’s personal awareness, skills and interest.

The aim of this research is represented by the second section: focusing attention on the solution; using a tool to create the “preanalytic vision” in order to produce sustainability solutions within the project boundaries and relying on the group’s creativity. In other words, turning sustainability problems that would need to be mitigated at a later stage, into creativity problems that prevent those issues before they actually occur.

Hence in a decoupled economy: what will products look like? How, where and who will produce them and through which business model will they reach users?

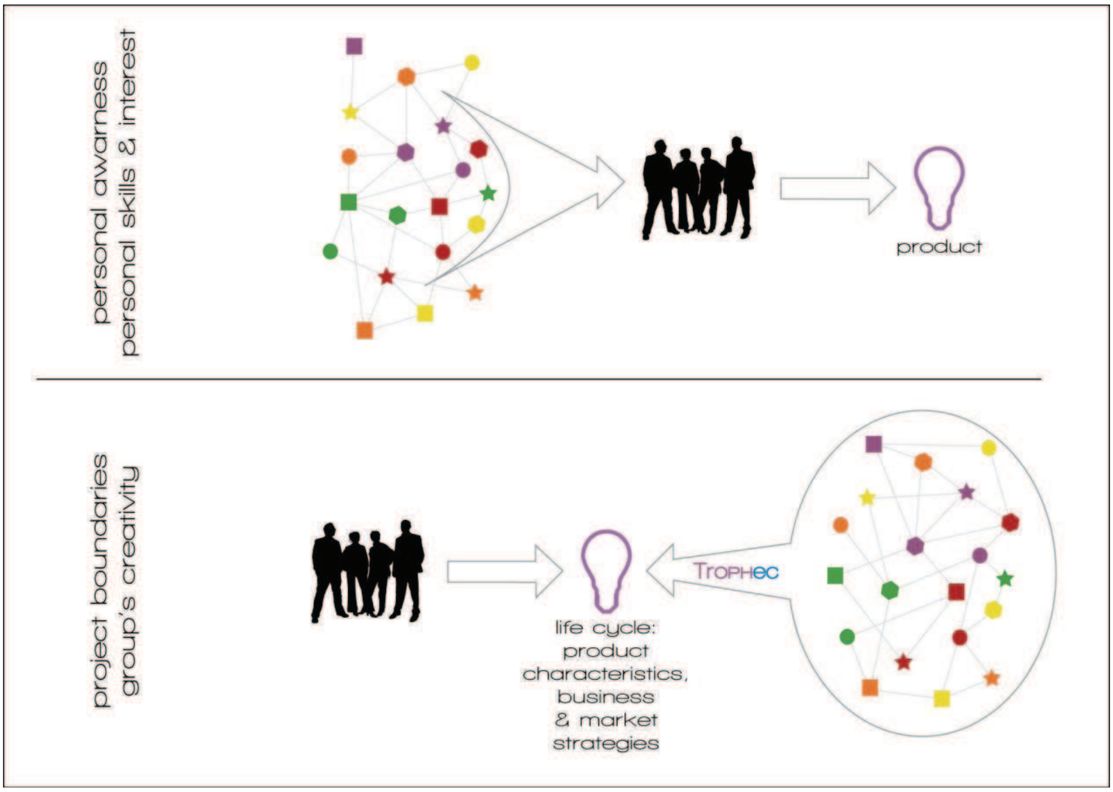

Figure 2 Facing complexity or focusing in the solution

Aims

This paper exposes the search for an intuitive soft modelling tool that considers multiple and complex factors in order to achieve long term sustainability and inspire the innovation of businesses and systems from a biophysical perspective. The aim of this tool is to enable the creation of a preanalytic vision, so that sustainability issues are revealed in response to the designers’ creativity and innovation.

Tool development

The first key question in the development of this approach has been: how does it work in nature? Organisms search for their food in other organisms, which at the same time become the food of others. Throughout this process biomass and energy are transferred from one level to another, losses occur, higher qualities of energy are created and all is maintained in continuous cycles (Mader, 2010). Similarly the linear human production of goods can be rethought by taking into account this basic principle of thermodynamics, although this is not a technological problem, the relevant constrains need to be integrated for this approach to be feasible. These are from an economics origin: how can a healthy business be achieved from a non-linear process? An analogy between natural and human systems is proposed: autotrophs = producers, heterotrophs (hervibores) = distributors and (carnivores) = consumers (figure 3). Also considered is their concentration and size, including all the possible combinations as well as their eventual business interpretations; this is referred to as Trophic Economics (figure 4).

The envisioned tool will combine the exploration of the complex factors involved in the lifecycle of a product with the suggested Trophic Economics models. The outcome could be referred to as sketches of the possible boundaries and structures of new business and products in their entire life cycle, to be resolved later on the drawing board (figure 5). Some of the factors are not directly related to the product or its life cycle, but rather to the context (country) where the raw materials will be extracted, where the product will be manufactured and where it will be used (figure 6).

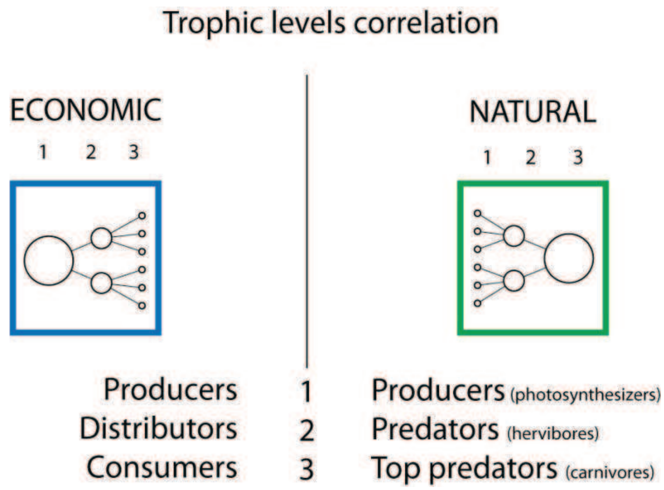

Figure 3 Trophic levels correlations

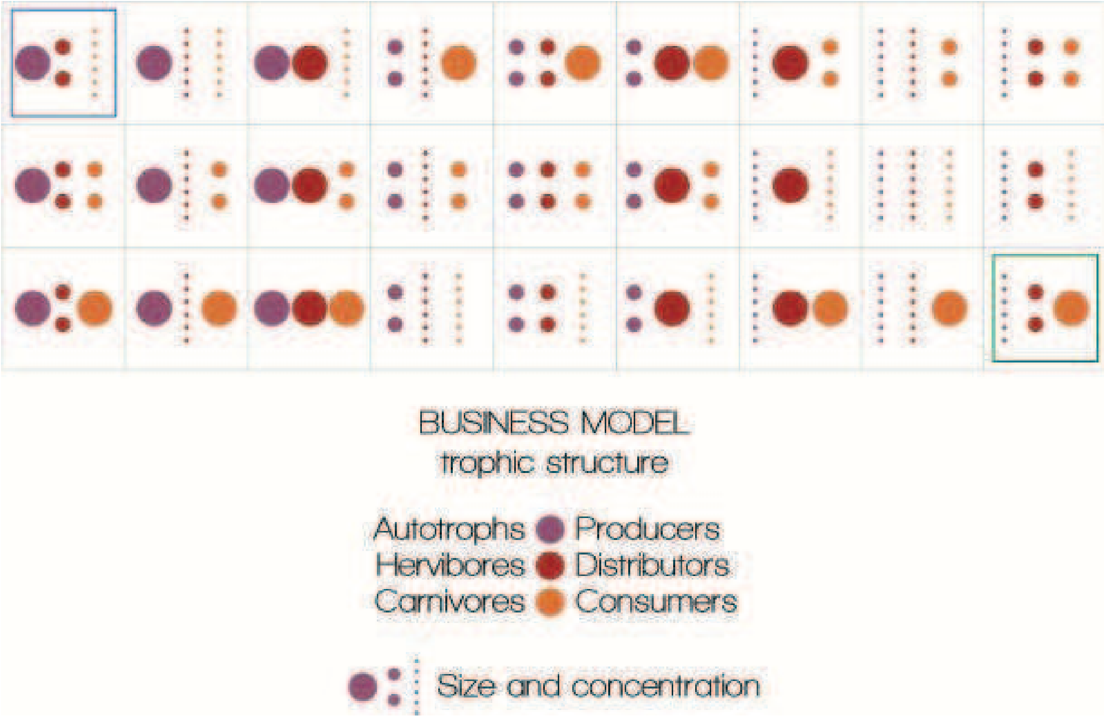

Figure 4 Trophic Economics diagrams

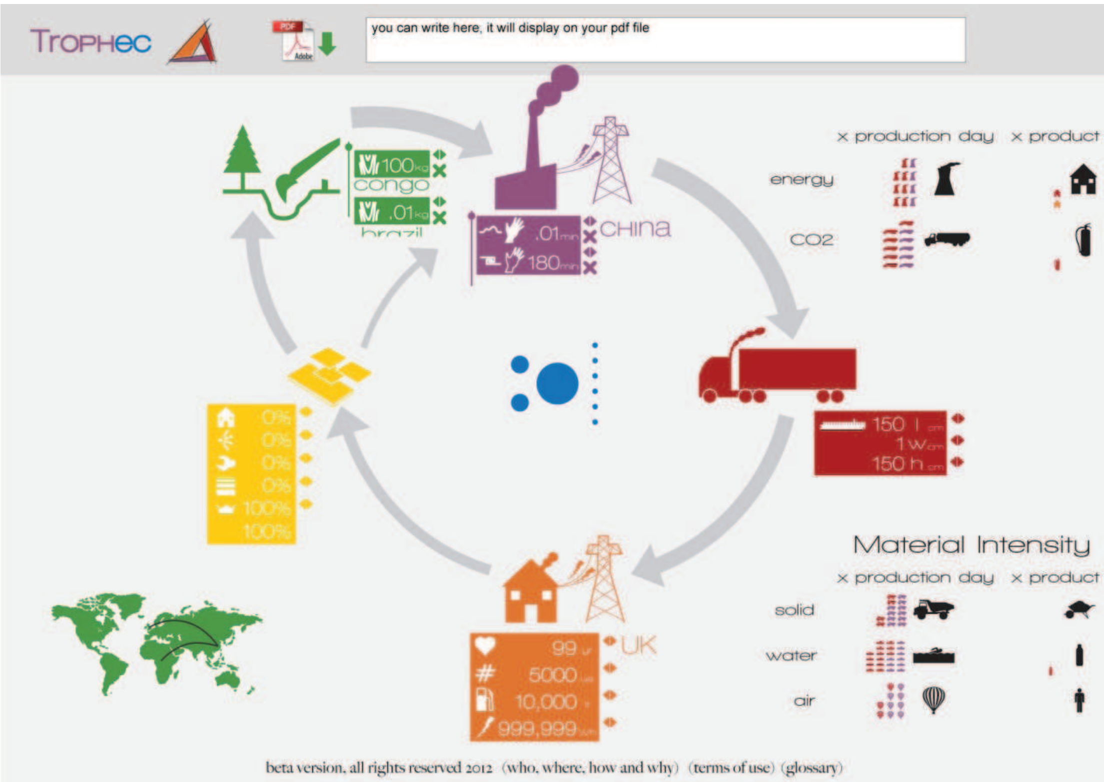

Figure 5 Life cycle sketch

The proposed tool's name is Trophec, as a short term for Trophic Economics. This is a web-based application that calculates the energy embedded, CO2 emissions and material intensity in terms of solid matter, water and air accounted by single product and for one day of its production. The tool operating model is based on the research on carbon and energy inventory of Hammond and Jones

(2008), the material intensity by Wuppertal Institute (Ritthoff, et al. 2002) and several indexes and data bases from: International Energy Agency, United Nations Environmental Program, United Nations Development Program, United Nations, The World Bank, World Resources Institute, Central Intelligence Agency from the U.S. government and the Department for Environment, Food and Rural Affairs from the United Kingdom.

The application allows the designer to visualise in simple terms the entire life cycle, including recycling, business factors and the impact these have on the above-mentioned calculations. The designer builds their sketch map (Figure 5.) step by step as they provide *estimates* or *known's* addressing each aspect of the cycle in turn. This content construction process is itself educational to the design experience, in enabling greater appreciation of factor interrelationships. Once the designer has completed the initial setup, all figures can be easily changed and in real time the impact visualised; for each set of results the user can save a PDF file; this is intended as the sketch of the life cycle and just like product sketching it is based on flexibility, speed and comparability.

These sketches are intended to be a playful way to create the preanalytical vision discussed previously, enabling designers to concentrate on what they do best: solving problems through creativity and innovation within the set technical and business boundaries.

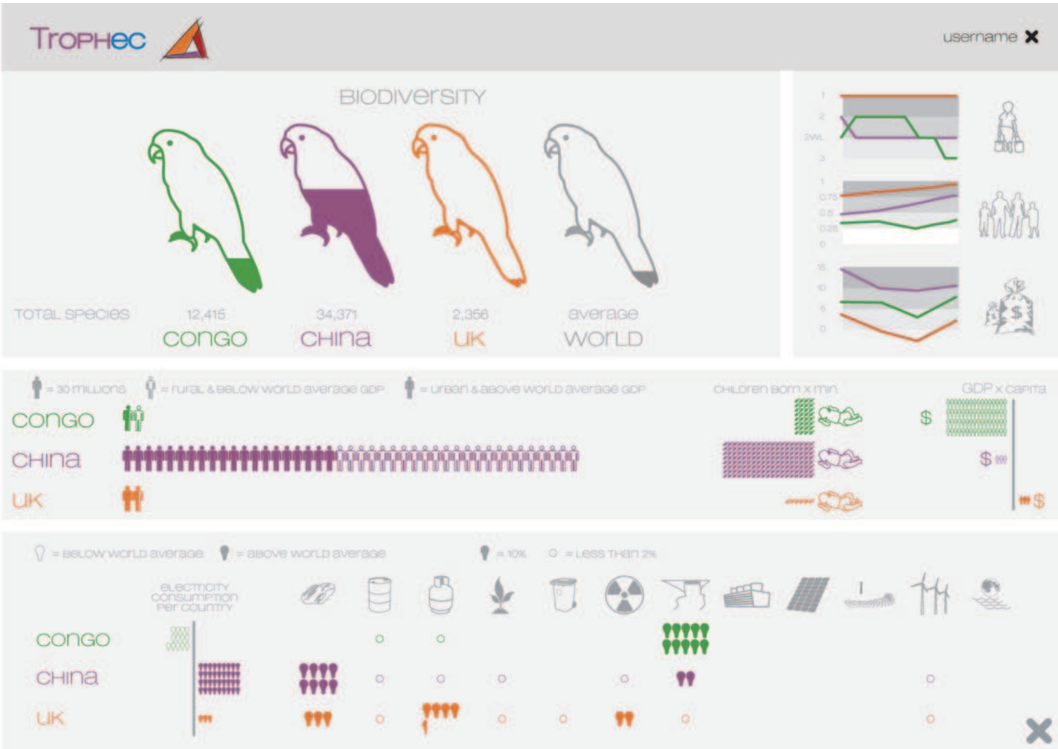

Figure 6 Countries infographics

A preanalytical vision, dynamically generated by the Trophec software integrates relevant economic, social, demographic and ecosystems information regarding the countries involved in any given sketch. Specifically: Biodiversity (total number of species), Child Labour and Slavery Tier, Human Development Index, national GDP, country population, urban and rural population, population growth, per capita GDP, country's electricity consumption and country's electricity production sources.

All this data is displayed as an infographic in order to make it visually concise and easy to use.

Conclusion

Many current sustainability problems are directly related to the way our macroeconomic systems are configured, in the way we produce, sell, use and dispose of products. Thus the design processes used to create them is at the top of the impact chain.

A number of tools and guides have been created to improve the sustainability of products, however these are dependant on individual designers' ability to process large amounts of complex data (fig 2).

By understanding the principles that allow long term sustainability in natural systems, (on which our macroeconomics system rely), we can transform our approach to product and business configuration, with the aim of achieving more equitable human development at the same time as releasing pressure on the depletion of the Earth's resources.

Therefore, as a response to these two statements, the need to create a preanalytical vision was discussed and to test this a tool has been developed. It is thought that this research could catalyse further discussions about the approaches taken by the design community and the future possibilities for design professionals.

Future work

The concept of Trophic Economics is in a very early stage, more research is necessary to better understand its correlations and implications in a possible integration to real-life business. It is not clear how this concept could empower local development by encouraging different business models of local and small but global enterprises, as well as its implication to resources usage.

Regarding Trophec, the tool will be tested internally in the School of Design at Northumbria University in the last months of 2012. At the beginning of 2013 it will be made public and design schools and various design professionals from all over the world will be invited to use it. The data gathered will enable us to better understand the creation of the preanalytical vision and its correlations and impacts on product and business design.

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