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Design Interventions, Prediction and Science in the Sustainable Transition of Large Complex Systems

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Abstract

The way that human beings live and consume the natural and environmental resources of the planet are not sustainable. Sustainability involves changes in individual beliefs, expectations, values and behaviours at the microlevel, changes in policy at the macrolevel of governments, and changes in the design of objects, social organisations and structures at the mesolevels. Design for sustainability has a big challenge: we need a ninety percent gain in energy and material efficiencies over the next thirty years. Bottom-up and top-down design and policy interventions are needed at all levels. These multilevel dynamics interact in ways not understood by conventional social and natural science: human beings and their physical environment form a bewilderingly complex multilevel system of systems of systems. The science of complex systems must, necessarily, conduct experiments through policy: scientists do not have the mandate or the money to perform large interventionist experiments. Policy can be construed as *designing the future*. Thus complex systems are entangled in both policy and design. We conclude that (i) the design professions impact on the community at all levels, and that ‘good’ design at any level is relative to design at all other levels, and the emergent design of the whole, (ii) design, complex systems science and policy must all work together to create a sustainable future, and (iii) policy and complex systems science must progress through a designerly way of thinking to achieve sustainable design coherently applied at all levels in the complex multilevel system of humankind living on planet earth in the decades, centuries and millennia of the future. This view puts design and complexity science at the centre of policy for sustainability.

1. Introduction

From jewellery and furniture to cities and the Internet, design and the creation of new objects and systems has characterised human evolution over many thousands of years. In the twentieth century humankind was shocked to realise that the artificial systems it creates at an ever-growing rate were having a global impact on the natural systems that are essential for life itself. In this context, *design for sustainability* has emerged as a concept that is applicable at every system level. In this paper we discuss the changing nature of

design for sustainability and discuss the need to shift interventions beyond eco-efficiency to focus on delivering new visions and outcomes for the effective sustainability of large and complex systems.

Our horizon of influence in creating a liveable world for future generations requires a shift in emphasis for design, from product and process to include policy and political process. Design and engineering in the context of sustainability needs to concern itself with enlarging the imagination of what ‘sustainability’ can mean in terms of giving form to the emergent benefits resulting from mutual generosity, mutual attention and mutual valuing. ‘Beyond eco-efficiency’ requires the science of the future to embrace design in the context of policy.

In this paper, policy is construed as *designing the future*, which involves objects, people and systems at all levels, from the microlevel of personal objects to the macrolevel of national and international infrastructure. Designing the small and the large increasingly requires the science of complex systems to anticipate emergent behaviour as systems and subsystems interact.

In the context of complex, multilevel systems, design for sustainability can be seen to address issues at all interacting levels. Global emissions of greenhouse gases at the macro-level will depend on the type of products and services individuals use, and how they are used, at the micro-level. Macro-level goal-setting and resultant policies will influence, top-down, individual choices at the micro-level. At meso-levels, organisations will specify and design products and systems that contribute to the complex whole. We suggest that the science of complex systems must embrace a designerly way of thinking [1] in the context of policy, and that together these interconnections provide the meta-level transition spaces and potential for the innovation required for creating sustainability today.

Unsustainability exists because of ill-conceived relationships between humans, large complex systems and the scale at which such relationships exist. The *root problem* in these relationships is the indiscriminate technical use of nature by humankind [2]. This paper explores unsustainability and sustainability through the scope of *design for sustainability*. It begins by introducing the scope of design for sustainability from the traditional view of eco-efficiency to the wider perspective of connecting the products and processes to the systems in which they sit. Transitions in thinking

about sustainability are described and linked to levels of design intervention at multiple scales, from material interventions (micro scale) to policy and planning and organization (meso scale) to self-organisation and goal setting (macro scale). An example of design at the micro level is discussed, as are the connections to other intervention levels and other ways of thinking about creating sustainability. This includes the concept of radical sustainable innovation and the implications of this on the design of large and complex systems. Linkages are then made between the science of complex systems and policy and the agency of design. Experiment is used to describe sustainability praxis. This connects to policy-level interventions as a way to build peoples' conceptual understanding of complex systems and as a vehicle to develop the awareness and skills needed to produce human-scale structures and experiences. Finally the paper concludes with a summary of the scope of design and policy interventions in complex systems and their potential to envision sustainable futures – futures that deliver positive outcomes for people and the planet.

2. Design for Sustainability

The relationship between design and the environment is ever-changing. Historically these links have focused on the improvement of material and energy efficiencies in both processes and products [3]. *Ecodesign* strategies such as material dematerialisation, reuse and recycling are increasingly common practice in modern-day manufacturing, as are initiatives addressing the reduction of energy use across product life. While such ecodesign strategies have been successful in reducing some of the environmental impacts of production processes and individual products, they have been less effective at delivering the larger efficiencies required for more sustainable levels of living. *These levels equate to approximately a ninety to ninety-five percent gain in energy and material efficiencies over the next thirty-year period* [4] [5]. These radical targets – termed *Factor 10* and *Factor 20* respectively - require a change in peoples' mindsets of how they engage with, use, and dispose of, the range of resources they currently rely on to meet their needs. These goals have huge impact across both production and consumption. They will be met in equal measure through changes in business and manufacturing practice, and initiatives that connect to why people consume, what they consume and how they can consume differently.

There are many ways of considering the design-environment relationship and how this interaction connects to ways in which we think and act. Donella Meadows [6], for example, discusses nine levels of intervention that can impact on a system: from the least impacting minor adjustments to a product, process or system, focusing, for example, on quantitative, measurable improvements in efficiency, or addressing new legislative requirements; to the most impactful interventions that arise from changes in the existing paradigm or mindset of that society – for us today it

would equate to deep challenges in the way in which we perceive of, and use, natural resources. John Ehrenfeld's vision [7] requires us to understand that activities concerned with eco-efficiency - making what exists a little bit better – are not adequate for achieving a sustainable society. *Reducing unsustainability* as he terms it, connects to Meadows' view of less impacting interventions: those of addressing numbers and finding meaning in auditing stocks and flows of resources. Designers and engineers have traditionally tackled 'environment' at this level. Instead, Ehrenfeld argues, there is a requirement for a new pattern of thinking; a pattern that is about *creating sustainability*, and about reshaping the rules of the system. This requires designers and engineers to think beyond their discipline and understand important connections to other ways of working and delivering different types of outcome.

3. Levels of Design Intervention

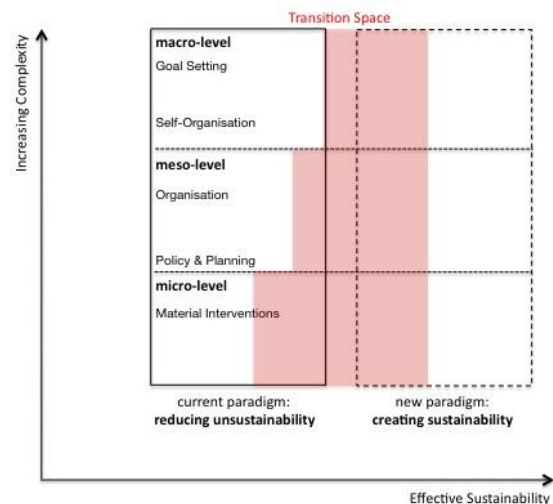


Figure 1 Design interventions for effective sustainability

Both Ehrenfeld and Meadows help paint a diverse landscape of the scale and scope of new types of thought and activities required for sustainability. This landscape is represented in Figure 1. Here we can see that a transition space exists: 1. between paradigms; and 2. across levels of increasing complexity. Rotmans *et al* [8] state that a transition is “... a set of connected changes, which reinforce each other but take place in several different areas, such as technology, the economy, institutions, behaviour, culture, ecology and belief systems ...” And in relation to different ways of thinking Ehrenfeld [9] adds “As long as we continue to hold our current beliefs as immutable, we cannot change the basic patterns of life that have become unsustainable. [...] We do, however, have power to change what we mean by reality and rationality by adopting a different approach regarding how we perceive worldly phenomena and then converting our perceptions into action.” Design interventions for effective sustainability embrace both interconnectedness (from technology and economy to personal behaviours,

beliefs and the ecological limits of a system) and human capabilities to imagine different ways of being and acting in the world.

Herein lies the potential for different types of design problem, process and outcomes to emerge from new interconnections and ways of seeing sustainability where “*opportunities for effective intervention may lie in the generation and circulation of elements of which variously sustainable practices are made.*” [10]. Figure 1 represents different levels of organization and types of design intervention and how they differ as the complexity in a system increases and the nature of the sustainability goals change across paradigmatic shifts in thinking. The underlying narrative here is that effective change involves multi-agency acknowledgment of responsibility; from the individual to the goal-setting political decision-makers; and that a *process* of design for sustainability (delivering outputs that support a transition from one way of thinking to another) transcends level, scale and things, to find new ways to envision, study and make sense of the inherent complexity of the systems.

3.1 At the micro-level Take the example of the redesign of a kettle. In the current paradigm an eco-efficient design response might address the nature of the material used (can it be minimized or substituted in any way), or find ways to improve the power used to boil the water, or better insulate the kettle so the water stays hot for longer. None of these *material interventions* produce ‘bad’ kettles, but equally, none of them help question: the many varieties of kettle in production; the inability to repair most of them; the disposable nature of these consumer products (and the millions like them); and the in-built culture of obsolescence. This is the nature of ecodesign interventions today: they do not question the fundamental problems of resource use and waste and the rate and scale at which they occur; they originate from a mechanistic mode of thinking concerned with, for instance: quantitatively measuring things; knowledge specialization *e.g.* understanding the parts in detail and not the whole; top-down regulation and control; and decision-making that rarely takes account of scale or place.

3.2 A systems view Now, let’s look at the same *micro-intervention* in the ‘creating sustainability’ paradigm. The problem again begins with the kettle ... but it doesn’t end there. The question is reframed to explore “why do we need hot beverages in the home and how else could this best be achieved?” The focus moves beyond product (it may well return to it) but explorations reflect a systems view in understanding resource flow in the home (hot water in this case) and how, as a result of this flow, people can most sustainably have a hot drink when they wish to do so. Hot water flow may already exist for heating purposes; it will already exist for washing purposes; it may be solar thermally generated; it may be stored in a very well insulated tank. Can any of these elements be re-configured to also deliver hot drinking water?

Alternatively, can peoples’ behaviour be changed to require less hot drinking water over time?

These are more complex and involved design problems that at one level may require technical and material input in the design of alternative solutions, but equally may link to meso-level issues of policy and planning in encouraging folk to think differently about water flow in the home. The key point of this example is that the initial part of the journey, although begun at the same starting point, alters dramatically depending in which paradigm the question is situated; and thus how the respective design processes are informed by *different value sets and rules.*

3.3 Charactering Radical Sustainable Innovation

The ‘creating sustainability paradigm’ – and design for sustainability activity within this – embraces an *ecological approach* in that its meta-narrative is one where the biospherical limits of our life-supporting system (Earth) governs and empowers decisions concerning the social, economic and cultural systems that exist within it. Such an approach can be characterized by qualities that have the potential to encourage sustainable learning and with it more *radical sustainable innovation* such as Factor 10+, for example: awareness of system; conceptual understanding and capacity building; being process oriented; problem-reframing; knowledge recognizing uncertainty and approximation; trans-disciplinary; self-awareness; democratic networks; human-scale structures and experiences [11]. In this context, design for sustainability requires ‘buy-in’ from all lifecycle stakeholders (including the ecological context) where effective buy-in will be heavily influenced by the ability of individuals to make sense of the goals of sustainability at a personal level. The efficacy of Factor 10+ levels of innovation will not only depend on high levels of self-awareness, but importantly, the ability to develop appropriate language, methods, tools and technologies that enable design and engineering disciplines to make sense of, and shift practice towards, Factor 10+ outcomes [12]. These types of intervention are situated across the micro, meso and macro levels of the system.

4. Social experiments in large, complex systems

The science of complex systems attempts to reconstruct the dynamics of systems from data. Observation shows that most systems have far from equilibrium dynamics and that rare but high severity events are common at all levels. Conventional science focuses on narrowly defined subsystems, artificially insulated from the effects of their environment. In 1956, Ashby wrote “*Science stands today on something of a divide. For two centuries it has been exploring systems that are either intrinsically simple or that are capable of being analysed into simple components. The fact that such a dogma as “vary the factors one at a time” could be accepted for a century, shows that scientists were*

largely concerned in investigating such systems as allowed this method; for this method is often fundamentally impossible in the complex systems.” [13].

The ideas of sensitivity to initial conditions, emergence and phase transition play an important role in complexity science. Most systems are sensitive to initial conditions, meaning that even if one had a perfect model of the system, inevitable measurement errors would make it unpredictable in the long term. The idea that small changes can have large effects is behind the theory of chaos and that managing systems far from equilibrium at the edge of chaos can give high performance but involves risk. In social systems group dynamics emerge from interactions between individuals, *e.g.* design process often involves teams of people working together to produce new objects and systems that no individual could produce by themselves. Much of conventional science and engineering are based on rules that capture precisely the usual behaviour but fail to capture unusual behaviour, *e.g.* Hook’s Law gives a precise relationship between the extension of a spring and its loading, but fails to predict the phase change that occurs when the spring is overloaded and the spring breaks. Phase changes and changes in state characterise complex systems – they can evolve from one state to another with completely different dynamics. From the viewpoint of sustainability this is a good thing since survival of the human species will depend on it adapting to radically different ways of living in the short time of a few decades.

4.1 Designing the future Policy formulation and implementation is a similar process to design. It begins with perceived requirements that the system *ought* to be different, and follows a process of generating and evaluating possible futures. As in design the initial ideas are hazy sketches that become instantiated with more and more detail until the predicted behaviour of the system can be evaluated against the requirements. As in design, competing constraints can only be satisfied to obtain a satisfactory overall compromise. As in design, the requirements are either under-constrained with too many options, or over-constrained and impossible to satisfy. As in design the requirements may change with the pragmatic acceptance that some desirable outcomes cannot be achieved and must be sacrificed in favour of others. The double cyclic generate-evaluate-re-specify nature of the design process provides a systematic way to accumulate knowledge about systems that don’t already exist. The implementation of designs continues this process as assumptions made during the abstract design phase may prove to be incorrect as the system becomes more concrete and unexpected problems necessitate new compromises in requirements and deviations from the original blueprint. The parallel between design and policy is so close that it is meaningful – and helpful – to say that policy makers *design the future*.

4.2 Embracing complexity in design Designers can be masters of complexity: they advise clients who don’t

know what they want on systems that don’t exist; they imagine new systems and work out how they will function; they know the components from which the new system will be constructed; they know which regulations apply to which parts of the design and how to satisfy the regulators; and they manage the dynamics of the finances and logistics of implementation. A programme of research into complexity and design [14] shows that (i) complexity science is required to design large complex systems, (ii) that the processes and procedures used to implement designs can be complex, *e.g.* manufacturing process and supply chains, (iii) that the environment of design is complex, *e.g.* fashion, economics, regulation, and (iv) the design process can itself be a complex cognitive social process. Perhaps more surprisingly the idea emerged that design, in the context of policy, is a necessary part of the methodology of complexity science [15] [16].

4.3 Complexity science and policy Generally complex systems scientists cannot do experiments because they have neither the mandate nor the money to change large complex social systems. For example, only policy makers in the public and private sectors can decide to build a bridge, divert a river, change financial regulations, or develop a new drug. Only policy makers have the moral authority and huge resources necessary for such projects. In its nature, policy to change systems and their dynamics into states never before experienced is experimental. Hindsight shows some of these policies to be reckless failures, illustrated by European fisheries policies and more recently poor financial regulation. Policy experiments based on conventional social and natural science can have unexpected consequences in other systems, *e.g.* recent policies on biofuel policy caused starvation while, more predictably, in the UK policies allocating children to schools has inflated house prices in the catchment areas of the better schools.

From a scientific perspective the problem with trial and error policy experiments is that they are usually not instrumented in ways that lead to new knowledge when they do or do not work. The best that scientists can achieve is to be part of the process that formulates and implements policy, and to instrument and observe the outcome to provide useful scientific data.

4.4 Policy Experiment in Sustainability and Design

Thus ‘Policy Experiment’ is the connection between complexity science and design. The role of experiments in creating sustainability is to enable better predictions for human and ecological wellbeing. However, the level for useful experiments needs to encompass not only the traditional zone of design and engineering - the micro-innovation of product and process technologies; but also the meso-level of social systems and infrastructure: the domain of policy and political decision-makers. Does this mean that policy-makers need to become designers and engineers; or that designers and engineers need to become more involved in policy decision-making? Perhaps. Perhaps in the future, new types of policy makers, engineers or designers will emerge that

synthesise a range of specialisms to foster change in each discipline base; to inform change in the way we plan for and implement real and artificial complex systems. In the meantime the focus for each community needs to be the development of a conceptual understanding of complex systems and the process-oriented and problem-reframing awareness and skills to build capacity for human-scale structures and experiences. The 'practical experiment' enables the interruption of existing (unsustainable) relationships and an exploration of the design brief, process, people and outcomes that help generate effective interruptions. To achieve transition to sustainability there is a need to seed all types of challenge through experiments at the multi-levels of large and complex systems.

4.4. The nature of experiment The example of the kettle redesign showed how current views encourage a materials response, rightly concerned with resource management, but not overly effective due to the 'system rules' that drive the large scale production and consumption of consumer durables. Situated in a new more holistic frame of thinking, the design intervention was broader: its concerns about water and energy flow at the household level and policies at the macro- and meso- levels direct Councils, organisations – and thus people – to behave in certain ways. The context becomes more than a container for boiling water; the process of thinking explores the interconnections of the system that support hot water in the home. Some physical form of kettle may be the end solution, but it isn't the fixed boundary of design thinking. The role of experiment in the multi-scale design-for-sustainability process is to provide insight and give form to the array of relationships within that system; and to predict behaviour and outcomes of relationships within systems that do not currently exist.

In creating sustainability the focus of the experiment is likely to be context, rather than process, when structures and sites of the multi-level complex system unfold. For example in the context of urban planning policy, boundaries for traditional design thinking at the material intervention and process level are set: from the types of street lighting to regulations concerning renewable technologies on buildings. The moral authority for change is situated at this organisational intervention level; something not familiar to many designers and engineers. Innovative thinkers however must realise experiments that are visionary, relational, technically feasible, ecologically sound and deeply connected to people and their needs. Whereas traditionally designers and engineers have been decoupled from their interventions it is now important, in a transition to sustainability, that these communities reconnected to the realities of social practices in which their technologies and designs are used; these "*social practices are not merely 'sites' of interaction but are instead, ordering and orchestrating entities in their own right.*" [17]. Thus social experiments are in flux: these are dynamic processes in which individuals are important in predicting – or designing their own futures.

It is through the deep understanding of metabolisms of behaviour in complex multi-level systems, and associated resource flows that designers and engineers can conceive new directions for the development and integration of technology to solutions that foster social and ecological wellbeing.

4.5 Designing social experiments Two examples of experiment illustrate the transition to sustainability. The first of these describes the UK and Ireland Transition Towns movement - an initiative addressing life after Peak Oil (the cheap and abundant oil supply on which the modern industrial world depends) and other global threats such as Climate Change. Under the umbrella of 'Transition' there are a number of social experiments concerned with generating positive ideas about low-carbon lifestyles. One of these is *The Totnes Renewable Energy Society*, (TRESOC) established to enable the UK town of Totnes and surrounding parishes to take charge of the development of renewable energy resources. The focus is to develop strategic capabilities to transform the energy supply infrastructure through constructive partnerships between community, government and industry [18]. This is a design experiment at the meso-level: the design of a network to supply and support existing low-carbon technologies at the local level. Simply having new technologies on the marketplace hasn't been sufficient to encourage take-up. Those designing such technologies need to recognize the importance of planning in, for example: encouraging changes in policy to provide incentives for uptake; developing educational and technical support material; creating opportunities for new connections across multi-systems; and developing technological interfaces to meet range of user needs.

The second experiment is the 2007 winner of the USA Metropolis Magazine's Next Generation Design Competition. Conceived by San Francisco's Design Collective, Civil Twilight, *Lunar Resonant Lighting* is a design proposal that asks us to think differently about urban light. "*Lunar-resonant streetlights sense and respond to ambient moonlight, dimming and brightening each month as the moon cycles through its phases.*" [19] Although this is an energy saving technical innovation, it's potential is enormous in challenging our perceptions of the value of lunar luminosity, in questioning our ideas of darkness and safety, and in mitigating light pollution and making accessible the cycle of the moon and the night sky. Such potential can only be realized if the intervention shifts to the meso level to engage with urban planning and design and with Government policy concerning safety and the built environment. Interesting ideas like these can only be made real with equally visionary thinking in the realm of policy design.

5. Summary and Conclusion

Sustainability is a complex systems issue, since it impacts on all the micro-, meso- and macrolevel systems, subsystems, and systems of systems that make up the human-technical-natural world. Sustainability in

one part of this enormous and complex system is determined by and determines sustainability in other parts of the system. Policy is seen as the process of *designing sustainable futures* informed by and informing complex systems science. Thus policy, sustainable design and complex systems science are inextricably entangled, and this has practical consequences for designers and design education:

- (1) The design professions impact on the community at all levels, and that 'good' design at any level is relative to design at all other levels, and the emergent design of the whole. Designers must think outside their narrow specialisms.
- (2) Design, complex systems science and policy must all work together to create a sustainable future: designers must embrace science and understand how their work fits within, and influences, politically determined normative systems.
- (3) Policy and science should progress through a designerly way of thinking – designers must communicate their knowledge, skills and methods to scientists and policymakers to achieve sustainable design coherently applied at all levels in the complex multilevel system of humankind living on planet earth.

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