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Bell, Chilvers and Hillier

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The socio-technology of engineering sustainability

1 **Sarah Bell** MEnvMgt, PhD
Senior Lecturer, Department of Civil, Environmental and Geomatic Engineering, University College London, UK

2 **Andrew Chilvers** MEng
EngD Candidate, Department of Civil, Environmental and Geomatic Engineering, University College London, UK

3 **Joseph Hillier** MSc, PhD
Research Associate, Department of Civil, Environmental and Geomatic Engineering, University College London, UK


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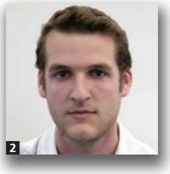
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Despite the social goals of sustainable development, including the alleviation of poverty, sustainable engineering approaches have been largely limited to technical measures, promoting engineers as purely technical experts. By under-emphasising social factors, this limits opportunities for engineers to address the full spectrum of challenges posed by the sustainable development model. We explain this in terms of the dominant policy response to environmental problems, known as ecological modernisation, which conscripts engineers into reinforcing false boundaries between technology and society. In contrast to the technical focus of engineering under a framework of ecological modernisation, we suggest that engineering can, in fact, be usefully seen as a hybrid socio-technical profession that breaks these boundaries. This point is underlined by the case-study of indirect potable water reuse, demonstrating that the acknowledgement of hybridity can be used to improve engineers' relationships with the societies they serve, and enhance the contribution of the profession to sustainable development.

1. Introduction

Sustainability challenges engineers to ensure social, ecological and economic issues are incorporated into their work. The seminal 1987 report by the World Commission on Environment and Development, *Our Common Future* (WCED, 1987) defined sustainable development as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs.' For engineers, according to the World Federation of Engineering Organisations, this entails 'planning and building projects that preserve natural resources, are cost-efficient and support human and natural environments' (WFEO, 2002). Engineers are pushed towards considering cross-generational costs and benefits of their work, the rights of diverse social groups to resources, and the shaping of consumer needs to fit environmental limits. Engineering can therefore no longer be characterised as a purely technical profession. Yet, while economic considerations have always been central to engineering decisions in a commercial context and in justifying public spending, and engineers have begun to address the ecological impacts of engineering developments, control pollution and minimise resource use, the social implications of engineering sustainability have proven more difficult to address.

This paper presents the need to reframe engineering as a socio-technical profession. The basis for this is acknowledgement of the role of engineers as mediators between technology, nature, society and culture, partnered with a recognition that clear separations between these domains cannot be achieved. Understanding engineering as a socio-technical practice enables a more effective contribution to sustainability than conventional accounts of engineering as a purely technical undertaking. This paper begins by looking at efforts by the profession to incorporate environmental considerations into a technical model of practice. It is argued that this engineering response to the sustainable development paradigm is closely aligned with the theory of ecological modernisation, which has been used to characterise the dominant policy responses to sustainability. More recent developments in engineering sustainability indicate that the profession is moving beyond the obvious need for green technologies and systems, to incorporate social concerns. In support of these broader approaches to engineering sustainability, the work of Bruno Latour is introduced as the philosophical foundation for a model of engineering practice which acknowledges the relationships between technical and social actors (Latour, 1993; 2005). A case study is then used in the controversy surrounding indirect-potable water reuse to highlight the importance of socio-technical approaches in making engineering decisions about future water supply options.

2. Engineering sustainability

In the past decade considerable gains have been made in incorporating sustainability into the everyday expectations of professional engineering. Sustainability is central to the Institution of Civil Engineers code of professional conduct, which outlines the obligation of professional engineers towards the general public, future generations, the environment and the sustainable management of natural resources. At the highest levels of the profession, definitions of sustainability acknowledge the need to address social as well as ecological issues. The 2006 sustainability protocol signed by the presidents of the American Society of Civil Engineers, the Canadian Society of Civil Engineers and the Institution of Civil Engineers states that:

> ASCE, CSCE and ICE believe that the current approach to development is unsustainable. We are consuming the earth's natural resources beyond its ability to regenerate them. We are living beyond our means. This, along with security and stability, is the most critical issue facing our profession and the societies we serve.
>
> In addition to the environmental impacts of our actions, the needs of societies around the world are not being met. Our goal as civil engineers is the creation of sustainable communities in harmony with their natural environment. In doing so we will be addressing some of the most profound problems facing humanity, for example climate change and global poverty, to name only two. (CSCE/ICE/ASCE, 2006)

The translation of engineering aspirations for sustainability into practical engineering tools indicates that concern with addressing environmental problems has resonated throughout the profession. The most prominent attempts to bring sustainability and engineering together are based on an approach which incorporates ecological factors into what might be labelled a traditional engineering model, resting on quantification, mathematical modelling and the application of physical science in order to achieve optimal outcomes. Technical specifications for pollution control, for example, enable the environmental impact of engineered systems to be objectively (i.e. mathematically) monitored and maintained within predefined parameters. Resource efficiency can be characterised as an extension of conventional engineering concerns with efficiency in design, previously driven by cost concerns but now more explicitly by environmental factors (Hawken *et al*., 1999). Holistic approaches to engineering sustainability based on systems thinking connect scientific principles developed to describe ecological systems to engineering methodologies developed in manufacturing, chemical processing, computing and large project management. Biomimicry in design and industrial ecology provide the clearest examples of the direct translation of ecological knowledge and models into sustainability (Allenby, 1999; Benyus, 2002; Yiatros *et al*., 2007).

Scientific and technical knowledge about ecological systems is more familiar to engineers than social and cultural issues and processes, and consideration of social and cultural dimensions of sustainability has been more limited in engineering practice. The Engineering Council UK (ECUK, 2009) in its *Guidance on Sustainability for the Engineering Profession* states that 'a purely environmental approach is insufficient, and increasingly engineers are required to take a wider perspective including goals such as poverty alleviation, social justice and local and global connections.' The social dimension plays a key role in conceptualising the suitability of engineered systems for different populations given cultural norms and economic and political realities. It also influences the success or failure of sustainability in more technical terms – for example, through the adoption or non-adoption of the sustainability agenda in particular fields or geographical regions, the need to match user expectations with system design, and predicting and shaping future consumption patterns. Fellows and Liu (2008) point out the importance of considering participants' values, which are grounded in culture, in understanding why the sustainability agenda in the construction industry has been largely limited to 'greening.' Their analysis of the broader policy agendas helps to explain why engineering practice is limited to incorporating environmental values and is much less successful in achieving the full potential of sustainability.

3. Ecological modernisation

The initial focus of sustainable engineering on providing technical solutions and new industrial management strategies to reduce the ecological impacts of development can be explained in terms of the policy context in which most sustainable engineering practice has taken place. Environmental policy in Europe and elsewhere since the 1990s has been characterised as promoting ecological modernisation (Barry, 2005). Ecological modernisation theory holds that technological innovation driven by appropriate policy and markets is essential to deliver radical improvements in resource efficiency and environmental performance, which will lead to the greening of modernisation. This section describes ecological modernisation and argues that, although it is distinct from sustainable development and is largely a political and economic theory, it characterises much sustainable engineering practice. Despite high-level recognition within the profession of the importance of social elements of sustainability, the most common tools and techniques for sustainability used by engineers seek to reduce the impact of current practices and thus approach sustainable development less as a reconfiguration of social and technological systems, and more as a technical challenge of enabling further growth within a materially limited environment. Ecological modernisation policy therefore focuses research and development towards more efficient and less polluting technologies. Commercialisation of research and knowledge transfer from research organisations to industry is assumed to drive greater economic as well as ecological efficiency, and will be guided by market demands, rather than policy constraints. Placing engineering practice within a wider policy context of ecological modernisation provides a framework for understanding why ecological efficiency has overwhelmed social concerns within engineering sustainability.

The emergence of ecological modernisation theory is largely attributed to Joseph Huber and his contributions to the environment and society debate of the 1980s (Murphy and Gouldson, 2000; Mol, 1995). It has emerged as the dominant political and economic position regarding the environment and has shaped regulatory regimes. Thus ecological modernisation has determined the environmental responses of governments, industrial sectors and corporations (Barry, 2005; Murphy and Gouldson, 2000). The central ecological modernist position places the solution to ecological crises 'in the direction of more and better modernisation.' (Barry, 2005, p. 304) This relies on the notion that economic development and ecological protection can be combined to synergistic effect (Gouldson and Murphy, 1997).

Ecological modernist policy sees the role of the state as 'enabling, co-ordinating and supporting, in terms of encouraging technological innovation and greater economic and ecologically efficient use of resources and energy.' (Barry, 2005, p. 308) It is left to private sector engineers to develop, test and market new ecologically efficient and innovative production methods. Environmental policy is thus limited to the supply side of industrial production focusing on the mutually reinforcing environmental and economic benefits of resource efficiency and waste minimisation (Christoff, 1996). This excludes engagement with issues of consumption in society and the demand for goods and services in the economy. Issues of equality and the societal distribution of production and consumption are also outside the boundary of engagement (Barry, 2005; Davison, 2001).

Ecological modernist policy has encouraged a drive in engineering towards environmental technology which enables engineered systems to consume fewer and less resources, to produce less waste (or to recycle the waste as inputs for further processes), and to generate maximum capital within legal and financial incentives to conform to environmental policy objectives. This has been complemented by the development of tools and techniques for the environmental assessment of products such as environmental risk assessment and life cycle assessment. Ausubel (1994) identifies three focal areas of environmental technology as industrial ecology, decarbonisation and dematerialisation. In a technological sense, ecological modernisation can be understood as 'any implementation of preventative innovation in production systems (processes and products) that simultaneously produces environmental and economic benefits' (Buhrs and Milanez, 2007).

More recently the ecological modernist focus in engineering has shifted, led again by Huber, from environmental technology to notions of eco- or metabolic consistency. This focuses on developing an industrial metabolism that is consistent with and can be situated within nature's metabolism (Andersen and Massa, 2000; Huber, 2000; 2004). The means of achieving eco-consistency remains the redesign of technological structures and infrastructures by engineers, however environmental technology is replaced by the broader notion of technological environmental innovations (TEIs) (Huber, 2004). Environmental technology can still be seen as belonging to a whole set of TEIs, however TEIs broadly aim to alter the upstream source of environmental perturbations. A selection of example TEIs covers some of the most prominent efforts of the engineering profession from recent years, including:

- the replacement of fossil fuels with clean-burn hydrogen
- the substitution of clean electrochemical fuel cells for pollutant furnaces and combustion engines
- fuel-less, renewable energy technologies such as photovoltaics, geothermal and wind
- enzyme and microorganism-based transgenic biochemistry for production tasks (replacing high temperature and pressure chemistry based processes)
- the use of low-hazard (biodegradable, environmentally non-persistent, non-acumulative and non-toxic) speciality chemicals
- ultra-light, ultra-strong materials that result in material and energy consumption savings
- micromachines and nanotechnology that relieve resource pressures
- circulatory production processes that recycle materials.

The delivery of TEIs is a significant focus of the modern engineering profession while also being the core element of the ecological modernist programme which seeks to maintain modern distinctions between science and politics, and the technical and social. This explicit coming-together of practice and policy means that completing engineering work that conforms to wider environmental policy also means maintaining these distinctions in engineering methodology and practice. Despite its importance to delivering ecological modernisation, under this model of environmental problem solving the engineering profession remains largely unconcerned by political and social debate. Instead it acts within in a policy context that distances it from engaging with the social aims espoused at the top institutional levels of the profession. Engineers are vital in leading technological innovation to reduce environmental impacts of development but are not involved in ensuring appropriate social conditions for sustainability.

Ecological modernisation consequently has two key limitations as a framework for sustainable engineering practice. The first is that the focus on supply-side solutions does not acknowledge the important role for engineering systems in shaping consumer demand for resources (Shove, 2003; Sofoulis, 2005; van Vliet *et al*., 2005). Second, by maintaining modern faith in the benefits of technological progress, it overlooks the social acceptability of new technologies, the capacity for populations to act unpredictably and the difficulties associated with balancing the rights of different social groups within a common environment.

These issues, as will next be argued, can be addressed by an alternative framing of engineering as a hybrid socio-technical profession. A socio-technical framework allows for better understanding of the relationship between technology, nature, society and culture and the role that engineers play as mediators between them. It provides a framework for analysing how engineering shapes society and how social concerns influence engineering and technology, thus providing a stronger basis for incorporating social as well as ecological and economic concerns into sustainable engineering practice.

4. Socio-technical engineering

The problems with the engineering approach to sustainable development have already been pointed out and it has been argued that these arise from a false separating-out of social concerns from engineering practice, which can be said to be broadly reflective of the dominant policy direction. The definition of engineering as an essentially technical profession is related to longstanding dichotomies that have been maintained between nature and culture, and science and society. This delineation provides justification for engineering as an objective, scientifically grounded profession, but does not account for the full breadth of engineering activity and influence. It supports a model of engineering as separate from social and political concerns. In this section, the work of Bruno Latour is considered, as a perspective that challenges these traditional dichotomies and provides a philosophy, situated in a broadly relational ontology, that engineers might look towards in rethinking their response to the sustainable development paradigm.

In his influential book *We Have Never Been Modern*, Latour (1993) argues that the separation of science and technology (technoscience) from politics and society is a central and classic characteristic of modernity. However, the division is an illusion: hybrid entities which at once embody technoscience, politics, society, culture and nature have always existed in our midst, despite being largely misrepresented and misunderstood. Latour contends that:

(*a*) the modern partition between nature and society is only possible because of the proliferation of hybrids which mediate between the two spheres
(*b*) the artificial erection of these conceptual boundaries provides difficulties when hybrid problems emerge.

Unable to account for hybrid phenomena by way of division between the supposedly pure categories, modern systems of knowledge and politics are not adequately equipped to understand and manage them. Climate change, according to Latour, is one such hybrid concern that mixes up elements of technoscience, politics and society, and crosses traditional boundaries between these and nature. We might posit the challenge of sustainable development, with its feet in social, environmental and technoscientific issues, as another hybrid problem.

According to Latour's viewpoint, standard accounts of modernisation, which form the basis for newer theories of ecological modernisation, falsely assume a clear separation between technoscience and culture. An engineering profession that seeks to solve a hybrid problem, such as sustainability, while at the same time positioning itself on only one side (the technical) of the false technoscientific–societal divide, therefore does not equip itself to deal with the true character of the problem. It can, in fact, be argued that hybridity and engineering have a long, if unrecognised, relationship. By transforming natural forces and materials into systems and products, engineers create hybrids and hence are active (indeed essential) in constituting society's hybrid reality, with both positive and negative implications for sustainability.

Thinking of engineering as a hybrid profession requires less a fundamental change in engineering horizons than a shift of mindset, yet this shift offers wide-ranging opportunities for reconsidering engineers' position in the drive towards sustainability. Defining this role under ecological modernist frameworks, which reinforce rather than challenge separations between technical, social and natural spheres, currently forecloses many opportunities for action to achieve sustainable development. In contrast, understanding engineering as both a social and a technical profession provides a basis for defining and developing the role of engineers in difficult socio-technical decisions constitute the major challenge of engineering sustainability.

Controversy surrounding the implementation of schemes for the reuse of wastewater in drinking water supply illustrates how problems arise from maintaining a firm distinction between technical and social concerns. The controversy surrounding indirect potable water reuse is in fact a hybrid problem requiring hybrid solutions. Propositions for more effective decision-making about potable water reuse show how engineers might help societies to move beyond unproductive adversarial debate produced by the separation of social, technical and environmental concerns.

5. Indirect potable reuse of water

Planned indirect potable reuse (IPR) is an option for alternative supply of water for utilities which have limited capacity to expand conventional supplies, such as abstraction from the environment or building new dams. IPR involves treating municipal wastewater to achieve high standards of purity and mixing it with water supplies, followed by conventional drinking water treatment. Treated wastewater, which would otherwise be returned to the environment, is therefore used to supplement drinking water supplies. The sustainability of IPR is contestable, but it has become an important option to be considered alongside greywater reuse, rainwater harvesting, demand management, desalination and other alternatives for improving water security in cities facing water shortages (Colebatch, 2006).

IPR systems operate in the USA and Europe, and have been proposed in Australia. The implementation of IPR has been the source of significant public controversy in the USA and Australia, leading to the cancellation or delay of some proposed schemes. Social acceptability is widely recognised as a key factor in the successful implementation of IPR proposals (Hartley, 2003; 2006). Hence, sustainability assessments and decision-making should consider IPR and alternative options against conventional sustainability factors (such as energy and resource consumption, cost, environmental impacts and health risks) but must also attend to the public acceptability. In the following case it can be seen that public involvement in decision-making about the sustainability of urban water systems and the role of engineers in these processes presents a significant challenge to conventional models of engineering practice and infrastructure management.

Debates about IPR have thus far been framed to represent technology and society as if they were two distinct realms. This ignores the complex relationships between the two and promotes an adversarial approach in dealing with the public controversy that surrounds IPR (Bell and Aitken, 2008). The technology of IPR, developed by engineers, is assumed to be stable and reliable, while the social world into which it must be launched is less predictable and beyond engineering consideration. Latour's framework allows us to move through the technology–society divide to see IPR as fundamentally 'hybrid,' neither purely technological nor purely social. Reconsidering IPR as a socio-technology looking to be stabilised within urban water systems, rather than a technology looking to be accepted by society or politics, provides openings for moving beyond the expert–public impasse and subtly shifts the role of engineers in decision-making about water supply.

In Australia attention turned towards IPR as a possible new supply during the prolonged drought experienced during the first decade of this century. In 2006 the city of Toowoomba in south-east Queensland held a referendum on a proposed IPR scheme. The referendum was the culmination of an intensely fought, adversarial campaign in which voters were required to choose between 'yes' or 'no' for a specific proposal, rather than being provided with the opportunity to deliberate over the advantages, disadvantages, risks and alternatives. Engineers contributed to this debate as technical experts on IPR technology and its importance as a new water resource, the politicians argued about the short- and long-term economic and environmental costs, and the general public acted as ultimate arbitrators of the debate, bringing to it social and cultural concerns, as well as vested interests. In the referendum 38% of residents voted in favour of the proposal, in line with long-term public attitude surveys in Australia and the USA.

A number of difficulties with this process can be identified, with particular reference to its underlying assumption that political and technical arguments can be easily differentiated. The binary form of the vote can be seen as a simplistic representation of what was a complex and controversial techno-political decision. This defied the reality that the translation of technical *fact* to actual decision relied on factors such as the voters' personal political perspectives, their environment, their willingness to accept risks inherent with new technologies, and the influence of those with interests in promoting alternative water schemes such as new dams. The stark yes or no choice denied the public the opportunity to deliberate over, and indicate the importance to them of, potential advantages, disadvantages, risks and alternatives of the IPR scheme. Engineers were hence taking part in a decision-making process that was inadequate for expressing the full range of views on the issue, and were unable to take account of these views themselves because of accepting a role as technical, rather than socio-technical, actors.

In response to the Toowoomba result and the prospect of a worsening resource situation, Queensland state premier Peter Beattie cancelled a promised referendum on IPR in the wider south-east region of the state, drawing on engineering expertise to support his decision. In 2008 renewed public debate in Australia about the health risks of IPR resulted in a further change of direction for this technology in Queensland with the new premier Anna Bligh announcing that recycled water would only be used in industrial, not potable, supplies. After several years of bitter public debate, the future of IPR in Queensland remains uncertain, despite the technical expertise of engineers in favour of this system. Whether or not IPR is the best possible solution to water shortages in Queensland, the case demonstrates that the model of engineers as technical experts in opposition to a concerned public is not a strong foundation for robust decision-making about controversial technologies.

The conventional depiction of IPR as a technological system designed by engineering experts who then present the technology to society and politicians as a sound alternative water supply to be either accepted or rejected, forms the basis of adversarial public debate and is underpinned by modern distinctions between technology and society. In such debates engineers are presented as technical experts in favour of the technology and public opponents as irrational, lacking sufficient technical understanding, or pursuing vested interests. As engineers reinforce the superiority of their technical knowledge over public concerns they contribute to the misrepresentation of IPR as a purely technological proposition and its opposition as purely social. This limited conception of the underlying causes of opposition has been criticised. For example, Russell and Lux (2009) attribute a problematic concentration on the so-called 'yuck factor' in discourses surrounding the debate to simplistic assumptions of causal relationships between purely emotionally driven cognitive factors and the opposition voiced. They find that this simplification characterised many of the survey-based techniques used during public consultation. A more constructive conceptualisation of the phenomenon reintroduces the socio-technical nature of the issues and recognises that values and meanings surrounding water supply are embedded in everyday practices, routines, habits and traditions, which are themselves inextricably shaped by existing technological systems and their preceding development alongside these cultural practices.

Engineers' primary role in IPR is clearly in developing the technologies. This is a necessary but not sufficient element of constructing sustainable water systems. Engineers are not responsible for devising appropriate public processes and institutions for considering proposals for new water supply such as IPR; however, engineers are responsible for devising publically acceptable, sustainable water supply systems. Rather than retreating to the purely technical definition of their role as experts in adversarial public debate, a more productive model of engineering practice could be to highlight the socio-technical nature of water supply systems and the need for institutions and processes which allow for technical and social considerations to be taken into account in decision-making. A socio-technical model of engineering practice would provide the basis for engineers to participate in public deliberation about options for sustainable water systems alongside other experts and members of the public, rather than carrying the burden of providing perfectly sound technical solutions which may or may not be implemented by society (Russell *et al.*, 2009). The controversy surrounding IPR indicates the fragility of balancing a purely technical role with social responsibility, and that engineers need to be socio-technically minded if they are to control their relationship with society at large, and hence their technology.

Reconsidering engineering as a hybrid rather than technical profession provides a starting point for developing new models of professional development and practice. These are more likely to succeed at incorporating social dimensions into sustainable engineering than conventional approaches which conform to the principles of ecological modernisation (and its focus on efficiency) and technological innovation. The work of Latour and others provides a theoretical framework to underpin the translation of the higher goals of professional institutions such as the ICE and ECUK into practice. A socio-technical model of engineering practice requires new knowledge and skills for professional engineers. Recent changes in the UK specification for chartered engineers to include sustainable development and a stronger emphasis on ethics show an increased awareness of these issues within the profession. Further support is needed through professional development activities to enhance understanding of social and political processes, community development and public engagement. Refining the socio-technical theory of engineering and translating this into practice requires further research in collaboration with engineers working in sustainable development and on projects with a high social profile.

6. Conclusions

Technological innovation is necessary but not sufficient to achieve sustainability. Ecological modernisation focuses on the potential for technological change to deliver sustainable outcomes without significant changes in how society and economies function. This theory can be used to explain the strength of the 'greening' agenda in engineering sustainability and how its dominance in the policy arena contributes to the deficit of models for incorporating social, ethical and political considerations in engineering, despite recognition of the importance of these issues by professional leaders and institutions.

Theoretical and policy frameworks such as ecological modernisation, which assign engineering to the realm of the technical, fail to account for the heterogeneity of engineering practice. They promote engineering practices that will continue to be disconnected from the full scope of the sustainable development goals that have been set at the top levels of the profession and are now widely held throughout. Sustainable development requires changes in society as well as technology, and the retreat of engineers from addressing the hybridity of this challenge, encouraged by policy frameworks, limits their ability for action. The current controversy surrounding potable reuse of water in Australia and other countries demonstrates the need for an expanded model of the profession which acknowledges the importance of engagement with social and political actors in devising sustainable systems.

Engineering is a hybrid activity and as such the profession has the opportunity to play a crucial part in ensuring that the hybrid challenge of sustainable development is met: producing innovative technologies, reconciling the needs of diverse social groups, changing cultural habits to fit crowded environments, helping the concerns of the general public to be represented in the technology they pay for and trust to serve their (and their descendents') interests. In focusing attention on technological innovation, as distinct from politics and society, ecological modernisation sells short the role of engineers in reconfiguring society and technology to achieve sustainability. Technical expertise will always remain the core business of engineers, but sustainable engineering requires a shift in how this expertise informs bigger decisions about infrastructure planning and resource consumption. Socio-technical approaches highlight the role of engineers in constructing, maintaining and occasionally demolishing the hybrids that mediate between nature and culture, and provide the grounding for stronger consideration of social as well as ecological and economic considerations necessary for sustainable engineering.

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