

SYSTEM INNOVATION FOR SUSTAINABLE BUILT ENVIRONMENTS: THE CASE OF LIGHT EMITTING DIODES

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Abstract

The United Kingdom (UK) government policy is increasingly directed at transforming the built environment to an environmentally sustainable one. The government, for example, has set a target for a reduction in carbon emissions by 80% by 2050 compared to 1990 levels. A large number of new policies and regulations are being introduced to minimise the impact of the built environment and the construction industry on the environment. These pressures are inducing a large amount of product and process innovation across distributed networks: manufacturers, suppliers, installers, clients, users, and so on. To address this challenge, this research suggests that the explicit adoption of a multi-level perspective of sustainable transition management as a way forward. The key point of the multi-level perspective is that transitions or long-term changes come about through interplay between processes at different levels in different phases. This model consists of three levels: socio-technical landscape, regime, and technical niches. This paper reports on an ongoing research project which is tracking, real time, the start-up and growth of a company which is developing and introducing a range of leading edge light emitting diode (LED) technologies. Interim results will be presented with the focus being on the distributed interaction between the principal actors: a LED module manufacture, a luminaire (light fitting) manufacture and a range of end users.

Keywords: High technology, light emitting diodes (LEDs), multi-level perspective, system innovation

INTRODUCTION

The United Kingdom (UK) government policy and regulation is increasingly directed at making buildings far more environmentally sustainable. A key source of environmental burden from buildings is lighting, which accounts for around 20% of the UK's energy consumption (Climate Change Act 2008; Carbon Trust, 2007a). The future consumption trend is upward, despite improvements in energy efficiency per lumens output. Projections indicate that the "global demand for artificial light will be 80% higher by 2030" (IEA, 2006: 26) and that particular "energy demand for domestic lighting ... [will] ... double between 2005 and 2030" (IEA, 2010: 14). The shift to more sustainable consumption patterns is not solely a technical matter; rather, it involves myriad changes in the institutional context, as well as the design, operation and use of lighting at building and urban levels. But appropriate technological innovation to develop more environmental sustainable lighting technologies is central to any credible, long-term effort to improve the situation. The current situation, for example, is one where "of the 628 million lamps installed in UK homes, around 60% use inefficient tungsten filament technology" (DEFRA, 2008: 7).

Light emitting diodes (LEDs) are poised to make a significant contribution to carbon reduction (BIS and DECC, 2009: 47) and “appear to have the greatest scope for improvement and may yet transform the global lighting market” (IEA, 2006: 42). This resonates with the Ad-hoc Advisory Group (2008: 12) which stated that, potentially, more than 50% of the electrical energy could be saved per year in the near future by switching to LED lighting.

LEDs are solid-state semi-conductor devices that produce light. LED technology has significant functional and environmental benefits over traditional lighting technologies such as incumbent incandescent and halogen technologies (TSB / DIUS, 2007). They have several major benefits [1]. First, LEDs have a practical operational life of ‘50,000 hours’ (Carbon Trust, 2007b: 12) compared with 1000 or 2-4000 for incandescent and halogen lamps respectively. This can potentially reduce maintenance cost. Second, LEDs exceeds the energy efficiency of conventional lighting technologies. For example, white LEDs are over 400% more efficient than incandescent lamps and 300% more than halogen (TSB / DIUS, 2007).

The better functional performance of LEDs, compared to incumbent technologies, is clear. But superior technical performance of a particular technology is no guarantee that it will become the dominant technology. Systems innovation (which adopts a multiple level, multiple actor perspective) is an important new stream of theory which is providing new insights into the innovation diffusion process; particularly ushering in a better understanding of why (and under what conditions) niche or disruptive technologies become (or do not become) established technologies in a given sector or technology field (for example, see Geels and Schot, 2007; Rotmans et al., 2001).

This paper reports on an ongoing exploratory research project which is tracking, real time, the start-up and growth of a company which is developing and introducing a range of leading edge LED technologies. A systems innovation approach is adopted to reflect on the interim results. The results reveal the pivotal institutional barrier of LEDs not being supported by national and international standards, as well as the obstacle of high capital cost in the procurement decisions at a local level. The interim results give tentative support of the value of using a systems innovation approach to understand uptake and diffusion a new technology. There is a need for significantly more theorising and empirical work in a built environment context to develop the descriptive and explanatory utility of systems innovation. This paper is structured as follows. Section 2 briefly discusses the multi-level perspective of sustainable transition management. Section 3 sets out the research questions and an overview of the research methodology. Section 4 presents the interim results with the focus being on the distributed interaction between the principal actors. Finally, discussion and conclusion are drawn.

MULTI-LEVEL MODEL OF INNOVATION AND SYSTEM TRANSFORMATION

Innovation theory and empirical evidence has long stressed that new technologies are the emergent outcome of a range of interconnected institutional and organisational activities. The linear view of innovation, for example, where new technologies are pushed into the market has been all but discredited. Further, there is recognition that the shift from the current, unsustainable trajectory of societies to sustainable paths cannot be achieved in a fragmented, ad-hoc fashion. There is a need for co-ordinated policy and action across a range of diverse domains and levels. In response to this agenda the multi-level view of system innovation is being developed. Geels and Schot’s (2007) multi-level perspective of ‘socio-

technical systems' on technological process innovation in the built environment distinguishes three conceptual levels: socio-technical landscape, socio-technical regimes, and technical niches (Geels and Schot, 2007; Geels, 2005) (see Figure 1). Each level is discussed below.

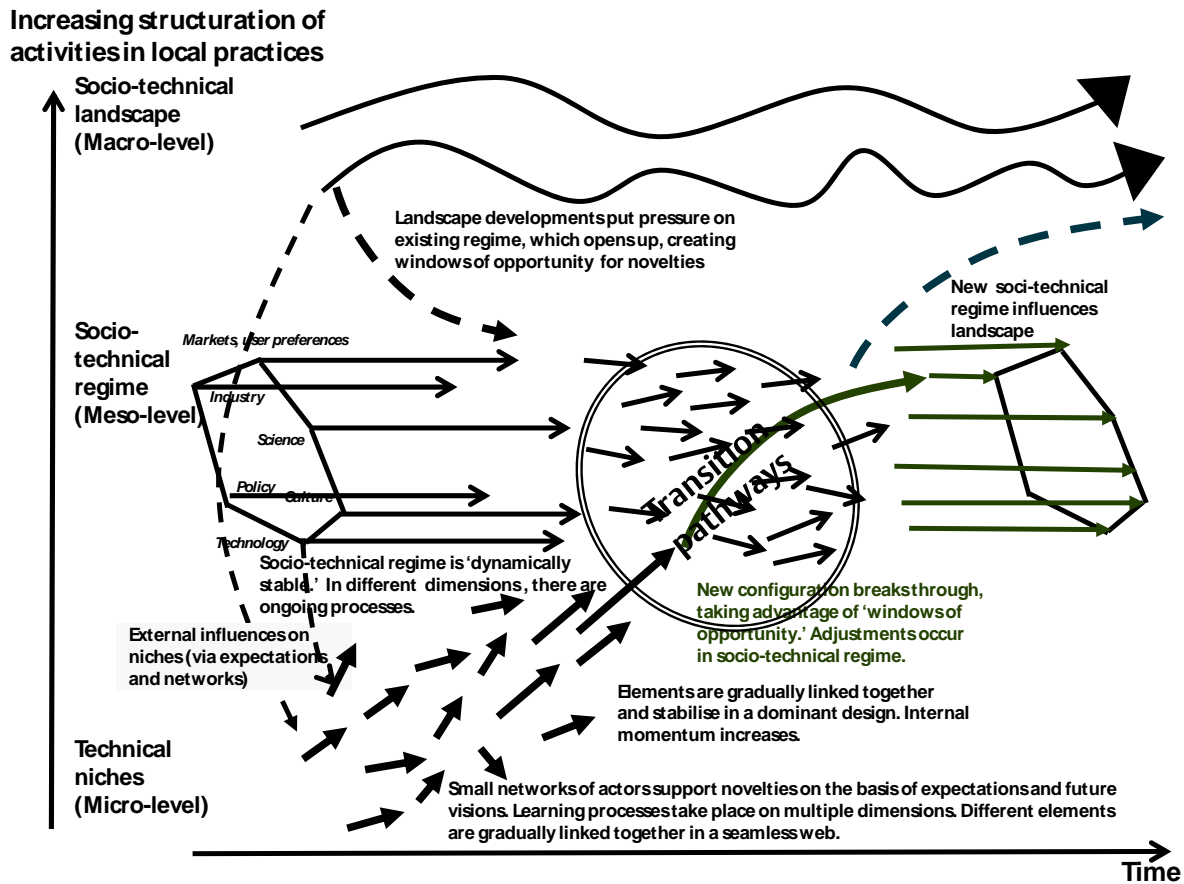


Figure 1: A dynamic multi-level perspective on system innovations (adapted from Geels and Schot, 2007: 401)

First, socio-technical landscape (macro) level represents the broader political, social and cultural values and institutions (such as standards, regulations) that form the deep structural relationships of a society and only change slowly (decades). The landscape guides actors' perceptions and activities. Within this landscape, there are socio-technical regimes and technical niches.

Second, socio-technical regime (meso) level represents "the prevailing set of routines or practices that 'actors' and institutions use and that create and reinforce a particular technological system" (Foxon et al., 2010: 1204). These practices include: "engineering practices; production process technologies; product characteristics, skills and procedures ... all of them embedded in institutions and infrastructures" (Rip and Kemp, 1998 cited in Foxon et al., 2010). Regime accounts for "the stability of existing large-scale systems (in transport energy etc.)" (Schot and Geels, 2008: 545). Within the existing regime, incremental, often product, innovation is generated.

Finally, technical niches (micro) level is where “market niches provide early footholds for radical innovation” (Geels, 2008: 522). Micro-level niches are ‘protected spaces’ where new technologies, new novelties etc emerge. Geels (2005: 450) further comments that it is difficult to create radical innovations within socio-technical systems because of the stabilising mechanisms. Radical innovations tend to be encouraged through regulation and/or financial incentives (such as taxes and R&D subsidies). For instance, the UK government is currently guaranteeing high prices for electricity produced by microgeneration technologies ^[2] to encourage the R&D, uptake and diffusion of such technologies.

The key point of the multi-level perspective is that transitions (long-term changes) come about through the interplay between processes at different levels in different phases. As a consequence, transition pathways ^[3] (see Figure 1) need to be created and managed to encourage the adoption and diffusion of ‘niche’ new technologies so that, overtime, they become the dominant technology. Geels (2005) argue that radical innovations emerge (the transition is) through three phases. In the first phase, radical innovations emerge in niches, often outside of the existing regime. There are no stable rules (e.g. dominant design) and actors improvise, and engage in experiments to work out the best design and find out what users want. The networks that carry and support the innovation tend to be small. Innovations at this stage do not form a threat to the existing regime. In the second phase, the new innovation is used in small market niches, which provide resources for technical development and specialisation. The new technology develops a technical trajectory of its own and rules begin to stabilise (e.g. a dominant design). But the innovation still forms no major threat to the regime, because it is used in specialised market niches. New technologies may remain stuck in these niches for a long time (decades), when they face a mis-match with the existing regime and landscape. As long as the regime remains stable, niche innovations have little chance to diffuse more widely. The third phase is characterised by wider breakthrough of the new technology and competition with established regime, followed by a stabilisation and new types of structuring. The multi-level perspective of transition management emphasises that “both internal niche-dynamics and external developments at regime and landscape level are important for wider breakthrough and diffusion” (Geels, 2005: 452) and transition pathways arise through the dynamic interaction of technological and social factors at these different levels.

RESEARCH QUESTIONS AND METHODOLOGY

The ongoing research is guided by the following research questions:

1. How does the lighting supply chain (including LED module manufacturer, luminaire manufacturers, specifiers and end-users) engage with new LED technology?
2. What are the drivers and barriers underlying end-users decisions to adopt / reject such technology?

The project brought together representatives from the key parts of the supply chain: LED module manufacture, luminaire (light fitting) manufacturer and end-users. A brief description of each project partner is presented below.

The LED module manufacturer, a small LED lamp manufacturer based in California in the United State of America, funded in July 2007, is a start-up company. Its business model is to

design and manufacture LED light modules that allows light fitting manufacturers to add significant value in multiple applications and markets which leverage their existing channels.

The luminaire (light fitting) manufacturer and installer, established in 1982, is an established original equipment manufacturer (OEM). It works with module (lamp) manufacturers and end users to produce standard and bespoke products and systems for a range of indoor and outdoor applications.

End-users include three technical and four non-technical end-users. Technical end-users include three specifiers (hereafter specifiers 1, 2 and 3). The specifier 1 was formed in 1978 and is one of the UK's largest mechanical and electrical (M&E) building services engineering consultancy practices. It specialises in bespoke building services engineering solutions to a wide range of market sectors, including healthcare, education, research, local government, pharmaceutical and commercial clients. The specifier 2, based in Scotland, is privately owned firm. The firm provides M&E building services engineering consultancy services. Specifier 3, also based in Scotland, is an electrical contractor.

Non-technical end-users include an airport operator, a property group, a regional museum, art gallery and archives service and an in-house maintenance function of a marina. The airport operator is the country's largest UK-owned airport operator. The pilot site (an airport) was located in North West England. The property group, founded in 1958, is an international property group with broad skills across the property value chain. The property group operates three core businesses: project management and construction, property investment management and property development. The pilot site (a shopping centre), opened in 1999, is Europe's largest combined retail and leisure destination. The third one is a major regional museum, art gallery and archives service. The organisation is responsible for twelve museums, galleries and heritage sites. The pilot site (a museum) is located in North East England. Finally, an in-house maintenance function of a marina. The marina opened in 2010 and is situated in Scotland. Its facilities include deepwater, sheltered berthing and built facilities, including accommodation, restaurants and bars and shops.

Data collection techniques include interviews, meetings, workshops and company documentation.

INTERIM RESULTS

This section is structured into two sub-sections: barriers to the adoption of LEDs technologies and enablers for the adoption of LED technologies.

Barriers to the adoption of LED technologies

1. High initial capital cost / high purchase cost

It is clearly LEDs has far better functional performance than the existing lighting technologies (e.g. tungsten and compact fluorescent lights), but the high capital costs was a major barrier. The 'high initial capital cost' of LEDs is clearly demonstrated by the comments of the luminaire manufacturer and end users. One of managing directors of the luminaire manufacturer, for example, expressed his concerns towards this barrier:

“As an overview, taking it above this [LED] technology, when it was going through ‘how do we get sustainable energy efficient technology in the marketplace, there is a tremendous

amount of negativity in the actual purchasing process of taking this technology on because of the initial capital cost, and that's the biggest barrier we face with this."

The 'high initial capital cost' strongly links to the second barrier discussed below.

2. Decoupled capital and maintenance budgets

When the capital and maintenance budget is disjoined within the client system, the adoption of LEDs appears to be impossible. This is evident in one of managing directors of the luminaire manufacturer, stating that:

"Where [a local authority] have the capital budget for expenditure is absolutely nothing to do with the maintenance budget, nor are they linked. Until the people who are in charge of the budgets for this link the two together to get an overall saving, their short termism is costing the country millions."

3. Lack of standards

Standards are playing an essential role in the growth of the LED lighting market and the rate of adoption of LED lighting in various applications. Without standards, performance comparison can be difficult or impossible, and specifications cannot be traced to a meaningful reference. This can make customers and specifiers uneasy about using LED lighting for their projects even niche actors' perceived that LEDs is fully developed. One of the end-users (specifier 2), for example, was skeptical of claims of LEDs' long life by saying:

"... the first criteria would have to be 'can I trust the life' ... that would be the first one because you get quoted lots of things ... a golden number of 50,000 hour life on a LED ... it's easy to quote a number ... it's hard to prove that number, I guess, isn't it?"

The importance to comply with regulations is further reinforced by one of end-users (specifier 1), stating that:

"... my experience here with people who have used LEDs has been quite open ... our engineers here are very open, forward thinking solutions. We do work within the realms of British Standards."

Lack of standards, particularly play a key barrier for the deployment of LEDs products in the construction sector. One of managing directors of the luminaire manufacture, for instance argue that unless the LED products is specified, otherwise, it will not be introduced into the construction projects.

".. when we're dealing with the design and build marketplace, the whole criterion of that is to get the most competitive tender in that satisfies your remit with a twelve month period, and this technology [LED], unless it is written in under design and build specification that it must have certain points, then it will never go in because the contractor will not pay eighty / one hundred pounds for a luminaire when he can buy ten or twenty pounds for a luminaire, and he doesn't care after twelve months of the problem."

4. Lack of awareness or enthusiasm of electrical engineers (e.g. lighting designers)

Electrical engineers can be significant influencers on LED purchases both by the choices they make for lighting fixtures in new construction, so lack of awareness or enthusiasm on their part can be a barrier to LED technology adoption. The resistance to change in designers and

clients to use LEDs, in part, because it would mean disrupting and changing the existing ‘regime’ or ‘way of doing things.’ Another managing director of the luminaire manufacturer, for example, indicated the challenge to introduce a radical technology (rather than incremental technology) into the development of new products:

“Our approach to product, because the lighting market place and engineers are conservative people who get very comfortable with certain pieces of technology, to move them radically in different direction becomes a problem to them ... so it’s easier for them to embrace the idea of a low voltage or a diachronic replacement ... let’s try and replicate something that works, that is more in their comfort zone to get a higher market uptake.”

Specifiers seek to offer leading-edge technology to their customer. LEDs are transforming their offer but at the same time introducing new challenges. Specifier 1, for instance, noted that:

“... there are always conflicting requirements, and the hardest one to reconcile is when it’s a personal conflict. I don’t mean personality, a personal conflict of somebody in a design team might prefer something else because they’ve used it in the past on another project and it was a really good result so they like that. You suggest something new, perhaps, and they may ... I wouldn’t say reluctance, but there may be a bit of ‘Is it okay? Do I really want to move to that?’”

5. Lack of awareness or knowledge of LEDs from clients

What was interesting is that, in most cases, the client itself does know what it wants prior to installation. It is only when the lighting installation is in place that the client knows whether it was the right or wrong solution. This situation is amplified in the case of LEDs as this is, in most cases, a totally novel technology for the client. The lack of awareness/knowledge of the client about the LED product is evident in the one of managing directors of the luminaire manufacturer and installer, stating that:

“I don’t know a single end user who would have any awareness at all [of LEDs]. In the old days when we used to talk about metal halides, people had firsthand experience ... now, with this, it’s just not on their radar ...”

6. No experience or having bad experience of clients of using LEDs

No experience or having bad experience of clients of using LED has negative impacted on the adoption process. This is demonstrated by one of the end users (specifier 1), stating:

“Sometimes a university ... may have a small project that doesn’t actually involve us, a small value project where they’ve bought a few LEDs, tried them, bad experience, and they’re not experts in the LED or lighting field, so they may just go with that as a bad experience and think ‘I’m not going to use them again.’ So that’s the kind of barrier that we might see.”

Enablers for the adoption of LED technologies

1. Whole life cycle costing

The ‘whole life cycle costing’ was considered as an important factor in introducing LED products into the project. Specifier 1 stated how the end user was convinced by deploying the new LED technology:

“The good thing for us is the energy departments ... specifically at University of ... their energy department is quite keen on using new technologies that save energy. With those product if I can save at least thirty or forty percent for certain types of products then it make sense to do so.”

That can be said that the concept of the ‘whole life cycle costing’ is addressing the both the ‘high initial capital cost’ and ‘disjointed capital and maintenance budgets’ barriers.

2. Reduction in maintenance works and low maintenance cost

The benefits of long life of LED products clearly demonstrate in the reduction of maintenance works and costs. This benefit to reduce the maintenance work was demonstrated by specifier 1, quoting how the new LED product was adopted by the end user:

“That was an architect. I showed it to the maintenance team after that meeting on site because I got to know them there, showed them the products, and the first thing they said was ‘Great. That means I won’t need to keep changing [lamps] that I keep changing every few months.”

3. The important role of specifiers

The important role of specifiers in helping end users’ acceptance towards new LED product is evident in specifier 1:

“Quite often when I employed as the specialist and are very seldom challenged on the design of the lighting, other than the way it appears with the design team, because the design team predominantly will include an architect. The architect on this one, I showed him the products because I was interested in it, of course, and I showed him the kind of output you get with LEDs and it was met with nothing but extremely open arms, such is the effect that the architect believed he would try to find as many jobs as he possibly could to use them on.

This is particularly when there is no LED standard in place. Specifier 1, for example, described the reason why he adopted the LED technology in his projects:

“It’s very difficult that one, isn’t it, because it’s hard to give me any concrete evidence for anything. I have to rely on the experts who are supplying it and whatever warranty they might provide to me. So on this project it’s a five year warranty, and that’s all I can really go on, actually.”

The interactions within social-technical regimes also present a challenge in the transition. One of managing directors of luminaire manufacturer and installer, for example,

“When you talk about end users, ...you talk to people who are lighting professionals and that’s what they do, they’ll embrace it, but, again, how well they communicate it to their client because, at the end of the day, the client after a while glazes over and just thinks ‘Oh yes, it looks nice. It’s pretty.’ He doesn’t know why it’s pretty.”

DISCUSSION AND CONCLUSION

The findings, when viewed through the multi-level perspective, bring into the sharp focus two key, interrelated issues. First, at a technical niche level, the current generation of light emitting diodes (LEDs) demonstrate clear functional benefits, but are significantly hampered by their high initial cost compared to incumbent lighting technologies (Unger, 2011). The

specifiers may be engaging with client systems to win the argument concerning whole life cycle cost attributes. But this engagement is very limited and patchy. Clients are locked into existing technologies and installation / maintenance routines which often lock-out consideration of the LEDs option. Second, at a social-technical landscape level, the specifiers are being hampered in two respects. Specifiers themselves may be locked in to particular lighting solutions. Further, where specifiers do consider LEDs, the lack of standards and certification schemes for the technology introduces too much uncertainty and risk.

This exploratory paper advocates that a broadening of the debate beyond the flat, linear view of, say, the traditional new product development to a multi-level perspective provides policy makers potential levers to bring about more effective system innovation. In this case, the LEDs technology itself is not the bottleneck – it is the way clients and specifiers are locked into old technologies and practices. The lock-in is further aggravated by the absence of LEDs standards and certification schemes. This is, in many respects, a somewhat common-sense message: technological innovation is not without context, it is embedded within landscape institutions and regime networks. But in the clamour for new sustainable technologies, this message is too often lost in the noise and, as a consequence, the system innovation required is not being progressed. In summary, LED technology, to substitute the incumbent, less environmentally-friendly lighting technologies, requires more robust transition pathways which are created and supported by legitimising standards and new knowledge sets for specifiers.

Finally, to reiterate, this exploratory paper has mobilised the multi-level perspective to construct a better, albeit partial, understanding of why and how new technologies (in this case LEDs) are adopted and diffused. We advocate that significantly more theoretical and empirical research should be undertaken to investigate whether the multi-level perspective has real purchase and traction in a construction context to move the sector to an environmental trajectory.

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NOTES

- [1] For more discussions on LEDs technologies, see Held (2009), Carbon Trust (2007b).
- [2] The term ‘microgeneration’ is understood to be the “... onsite generation of low- and zero-carbon heat and electricity in domestic, public and commercial properties (Bergman and Jardine, 2009: 6).
- [3] Transition pathways are defined by “the interactions between the internal regime dynamics and wider landscape factors and niche alternatives, which destabilize the incumbent regime and eventually give rise to a new regime” (Foxon et al., 2010: 1207).

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