BRUNEL
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LECTURES

Institution of Civil Engineers

Beyond rhetoric

Delivering a low carbon society

The Institution of Civil Engineers
Brunel Lecture Series

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ATKINS

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Introduction

If we looked to devise a problem whose complexity and scope humankind would find the hardest to address, it would look like climate change. Climate change puts us, as an engineering profession, at the threshold of the biggest fundamental change to our economy and society since the Industrial Revolution.

The move away from a societal dependence on fossil fuels as its primary power supply is a modern imperative. The delivery of a low carbon economy requires a new industrial revolution and this revolution is first and foremost associated with technical innovation - it is not a regulatory challenge. Thomas Friedman in his excellent book *Hot, Flat, and Crowded* states that the new green revolution is “ultimately... going to have to be solved by the engineers”. However, to successfully deliver a low carbon economy not only must we consider how to minimise our reliance on fossil fuels but also how future designs will take account of rapidly changing climate; mitigation and adaptation.

In substantially reducing our dependence on fossil fuels it does not matter if we consider the driver for change to be:

- man-made global warming (where the science is increasingly resilient)
- the need to improve energy security (leading from a combination of high levels of reliance on fossil fuel imports and geopolitical uncertainties) and
- the closely related issue of food security, or the cost of fossil fuels (due to increasing costs of extraction and the impact of ‘Peak Oil’).

Each of these imperatives has a different timeline but all require immediate thought and action.

We must also understand the true role of the engineer; what do we actually control or influence? The concentration on these key issues will enable us to deliver change at the speed required and to avoid the distraction of worthy debate on the origins of climate change. Similarly, it is not our responsibility to try to engineer a utopian vision of society (or to engineer austerity): what we are trying to do is to use our abilities as engineers to reduce the quantity of fossil fuels required to power our society, to deliver renewable sources of power to meet our continued energy requirements and to provide design choices that meet the demands of a low carbon economy. This must be reflected in the way we work as well as what we produce.

To help us do this we need to value energy in a different way, in particular the way we account for it within the projects we design and deliver. We must reflect local conditions and circumstances but share knowledge and information wherever we can.

The necessary speed of change is such that we need to get on with it and be prepared to make mistakes.

The last industrial revolution was based on coal (and the resulting exponential rise in burning of fossil fuels is actually the source of today’s problems). The next industrial revolution will be based on low carbon electricity.

De-carbonising the global economy and the progressive delivery of a low carbon society is effectively about understanding and managing carbon dioxide (CO_2). The control of atmospheric levels of CO_2 requires that we change our primary fuel source from the combustion of fossil fuels to electricity generated from zero or ultra-low carbon sources. The consequent, almost universal, electrification of our energy supply will cause a significant re-balancing of the built environment and the development of a new energy infrastructure. As engineers, we can map the infrastructure changes that will be required and there is a growing appreciation that carbon dioxide (and the basket of six greenhouse gases) quantified as CO_2 equivalent (CO_2e) must become the primary design determinant for new build and retrofit activities alike.

International agreements

There is widespread disappointment over the failure of COP15 but the scientific work, together with social and political movements that got us to Copenhagen, are in themselves astonishing.

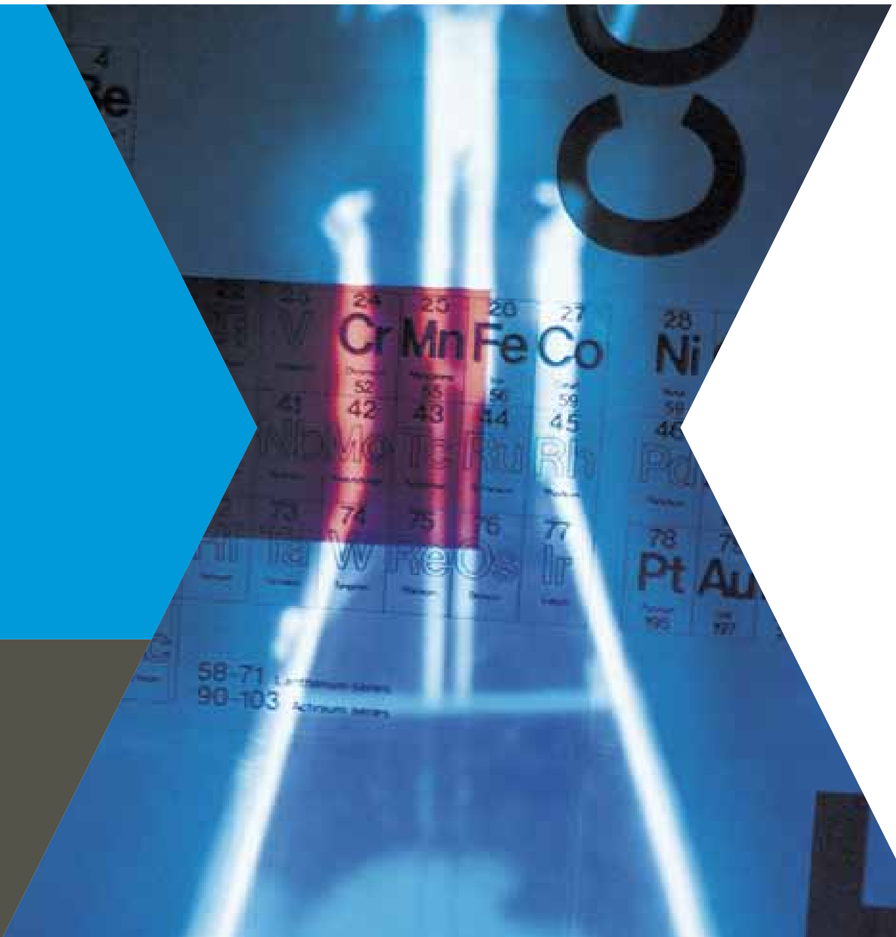
The Copenhagen Accord, now signed by 126 countries (which account for 85% of CO_2e emissions worldwide), is a good starting point and an optimistic one. A binding agreement was never remotely likely, not because of need, desire or merit but the sheer logistics of multi-faceted negotiations between multiple groups is structurally doomed without a dominant player or two.

However, for the first time all major developed and developing economies have agreed that their respective national GDP growth cannot continue without a radical reduction of the greenhouse gases (GHG) that to date have been a fundamental characteristic of our post industrial growth.

The signatories to the Accord have agreed we need to limit the average global temperature rise by 2°C. The Accord is unequivocal in that this is the maximum desired outcome. This in turn leads to the limiting of the equilibrium concentration of carbon dioxide to around 450 ppm.

This Accord is an excellent achievement in its own right but more importantly, the “COP15 Crash” has removed the constraint of needing to get a legally-binding agreement of the management of CO_2 emissions before moving ahead. As a result, this has encouraged many governments to do so, possibly at greater pace. We maintain a high level of optimism for further agreements in Cancun (COP16).

So what do we, the engineers of the built environment, have to do?



CO_2 as a global pollutant

Carbon dioxide (CO_2) pollution has had a significant negative impact on the physico-chemical characteristics of the atmosphere and the oceans. These changes have consequences. Each country will have a different level of ability to deal with these consequences (adaptation) but to limit the scale and cost of these - potentially very severe - consequences, we must address the cause as well. Our focus, therefore, is to reduce the emissions of polluting CO_2 into the atmosphere. To do this we need to reduce our reliance on fossil fuels and move to an economy based on 'clean', low carbon energy supplies. At an international level we have to make these types of changes to our air quality in relation to other combustion pollutants.

The first Industrial Revolution caused major changes to the air quality within towns and cities in the UK. The main cause of this air pollution was the burning of coal, not only by power stations and factories, but also, on a massive scale, by domestic households. Legislation was slow to come and over 12,000 people died in London as a result of the smog in 1952. The Clean Air Act was passed in 1956, death rates dropped quite quickly and a significant amount of pollution ceased with little economic disruption or technological risk. Through the Clean Air Act we managed particulate emissions in the UK and we have lived for many years without smog and the associated lung disease. We continue to this day to pass legislation that improves local environmental quality forcing us to engineer a solution (which we are rather good at). This creates a sawtooth profile of incremental solutions all based on solving a well-defined problem.

The management of global atmospheric levels of carbon dioxide is rather different, not just in the scale involved but also that we have been seeking pre-emptive action. We are now trying to pass the Act prior to "smog" occurring and many won't understand why it's necessary. It's not just London or the UK that will be polluting your air; it's everybody with any serious economy. They also need a similar Act to make your pre-emptive Act effective.

Continuing with the smog analogy still, imagine smokeless coal is unproven, its price fluctuates widely and while some improvement is possible by better fireplaces and brushing chimneys, the degree of improvements that we anticipate are required go beyond affordable, available technology and know-how. We are therefore introducing uncertainty; we are asking somebody to take a risk. Lastly, physical manifestation of cleaner air can be remembered and valued. In the transition to a low carbon economy, we are saying all the changes will do is make a range of catastrophic scenarios, possibly for those elsewhere in the world, less likely.

There are a small number of important global-scale successes. We have delivered international agreements to greatly reducing ozone-depleting substances (which has allowed the hole in the ozone layer to be repaired) and we have made massive improvements associated with the international impacts of acid rain from poorly managed emissions of sulphur dioxide and oxides of nitrogen.

In relation to CO_2 we are now considering the pre-emptive implementation of agreement and law to a predicted problem (and this is really the fundamental basis of the counter-arguments). This time we won't have industrial emission limits to work within, but we will have carbon budgets that relate to the carbon embedded within the materials that we use and consume, during the long-term operation of the built environment. National regulation to limit CO_2 pollution is possible (e.g. UK Climate Change Act 2008) but we have not secured international agreement on limiting the mass emissions of CO_2 or to control its concentration in the atmosphere.

What does 2050 look like?

It is impossible to provide a precise picture of 2050. We cannot say that there will be 1,000 of these and 150 of those, as the quantum is impossible to calculate. At the moment we can only consider 2050 to be an electrified society that is resource-constrained (fossil fuels, water, non-renewable materials, agricultural land).

If we are to change our primary fuel source from coal, oil and gas to electricity generated from renewable sources (we're including nuclear in this) we can create a broad vision of how this electrified society will be powered. We can also envisage that the universal electrification of our energy supply will cause a significant re-balancing of the built environment and the development of a new energy infrastructure.

Secondly, we must design with an ever-decreasing whole life cost of carbon (i.e. embedded and operational).

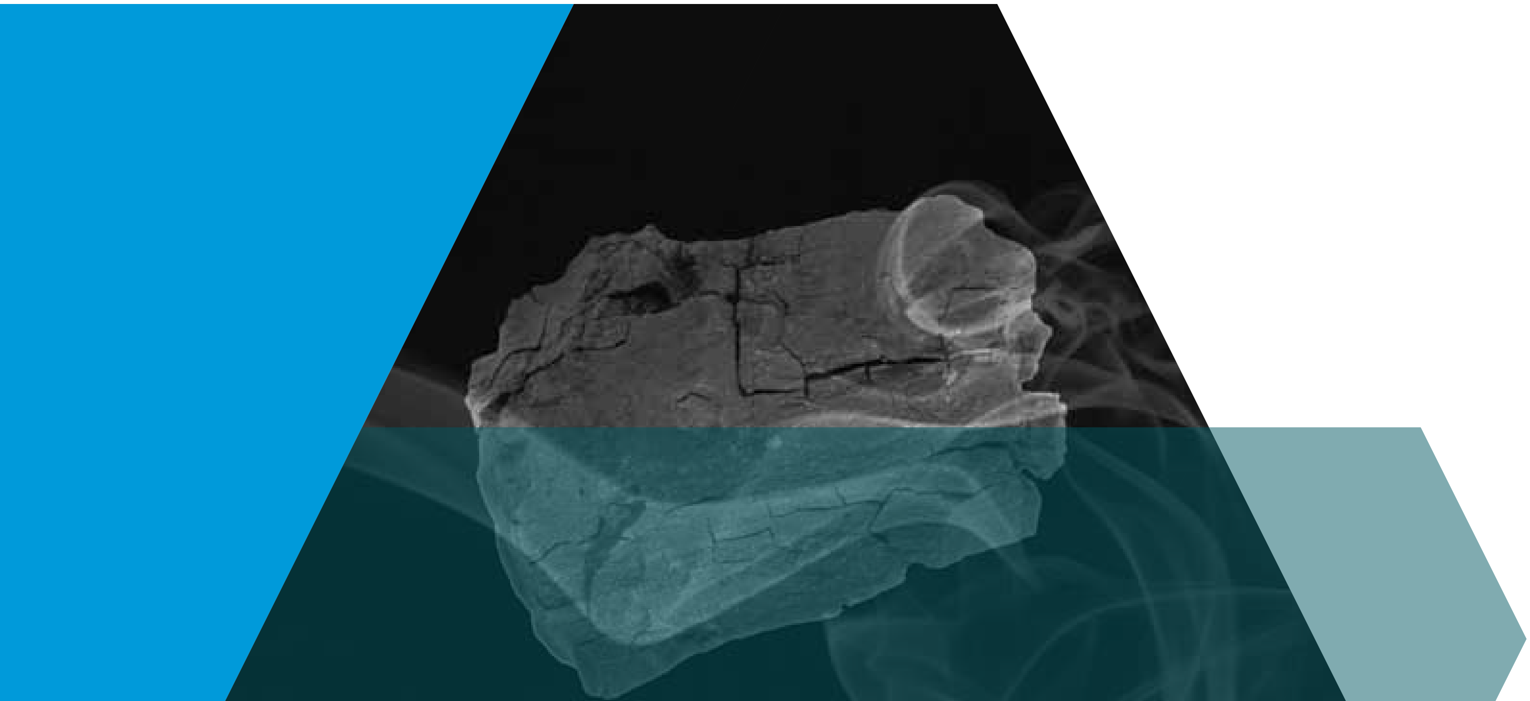
Thirdly, we must design the built environment for potentially radically-changing environmental conditions. In the UK we expect warmer, wetter winters; hotter, drier summers; rising sea levels and more extreme weather events: quite mild when considering the potential impact to which many others will be subjected. Whilst a 2-degree-Celsius increase in average temperatures doesn't seem much, we will have to move from a position of mass heating to one of mass cooling.

We can envisage that societies within nations and across nations will become more polarised. There are likely to be two extremes of society - increasingly urbanised with high levels of integration, or rural with high levels of self-reliance.

There are too many unknowns at the moment, we are dealing with levels of risk and probabilities, and this means that we can only envisage 2050 as a state of mind.

Low carbon engineering must be delivered in conjunction with high-quality design where we still desire and produce elegance and simplicity. The low carbon society will not be a return to poverty and donkey carts. We will continue to promote low carbon GDP growth and leadership in this new economy, which will be a significant source of new, green jobs. The only constraints being applied by the engineer are in the use of fossil fuels both operationally and embedded in materials, though others will be considering farming practices, land management and animal husbandry.

As a minimum we must provide a society in which we actually want to live, as well as one we can hand on to our children and grandchildren without shame.



Control and management of CO_2 emissions

If we imagine a world where carbon budgeting is the norm then we can start to get an appreciation for what changes will be required in the way that designers and engineers work. To meet a carbon budget we must be able to design on the basis of carbon as the primary determinant, go back to first principles in relation to design approaches and think in a low carbon way. Carbon budgeting may even equate to the rationing of CO_2e in some circumstances.

So what happens if we agree that we have carbon reduction targets to meet? In many ways it doesn't matter if the reduction is 60% or 80%, it's going to be a very big number. These targets cannot be delivered in a haphazard way and we should prepare for the application of carbon budgets. These budgets may be applied at a national, sectoral, company, or even personal level. We have to think about:

- How we can use less energy to reduce the energy gap that must be met from renewables
- How we will substitute the energy that we use to keep our society running (day-to-day energy usage or operational carbon)
- How we should invest, within the fabric of the built environment, the carbon that is available to us (i.e. embedded carbon).

High levels of atmospheric CO_2 originate from an extraordinarily wide range of human activities, but many of these are not the direct responsibility of the engineer. For example, population control, the widespread consumption of red meat or how we create financial systems which seek to deliver equality in carbon usage are not the responsibility of the engineer.

It has been agreed internationally that we need to reduce our consumption of fossil fuels and therefore the emissions of GHG by at least 50% in total by 2050 but we need to consider what this means for each sector in more detail (consideration of Peak Oil may drive this even faster). We think we can reduce CO_2e usage by 15% to 20% by simply applying what we already know. The next 30% will require product innovation and massive investment in low carbon energy supplies.

Even a simplistic analysis of this data shows that a 50% across-the-board reduction will not be feasible: we still have to produce food.

Working with carbon budgets we, the engineers, must:

- Effectively de-carbonise the energy sector (a >75% reduction in GHG emissions, whilst allowing for major carbon investment in new renewables and the transmission and distribution grid)
- Halve the carbon used to operate commercial buildings whilst allowing for carbon investment in retrofit and new build)
- Halve the carbon used to operate the transport sector (whilst allowing for mass electrification - which will also reduce operational emissions)
- Allow for an increase in the use of carbon in the public sector to take account of investment in the infrastructure
- Halve the carbon used to supply the residential sector (whilst allowing for carbon investment in retrofit and new build)
- Significantly improve the carbon efficiency of the industrial sector whilst recognising that we will need to use oil as the base material for many essential products
- Significantly improve construction and manufacturing efficiencies to avoid waste generation.

Adaptation and design for future climate change

Working to minimise the rise in global average temperature is not enough on its own. Even if the growth in global emissions could be stopped immediately, the effect of past emissions would continue to be felt for decades. A 2°C temperature rise (arguably the best that can be achieved) would inevitably lead to some changes in climate. The higher the average temperature rise, the more significant the associated climate changes and the greater the potential impacts on our natural and human environments. Hence, an integral part of the transition to a low carbon economy must be the delivery of design changes to buildings and structures that will help us adapt to a changing climate.

The physical manifestations of climate change may be the effects of high temperatures, increased incidence of flooding, strain on water resources and water quality, and less stable ground conditions. In addition to gradual changes, we are likely to see an increase in the frequency and magnitude of extreme events. These events will impact on our 'critical infrastructure', see **Figure 1**.

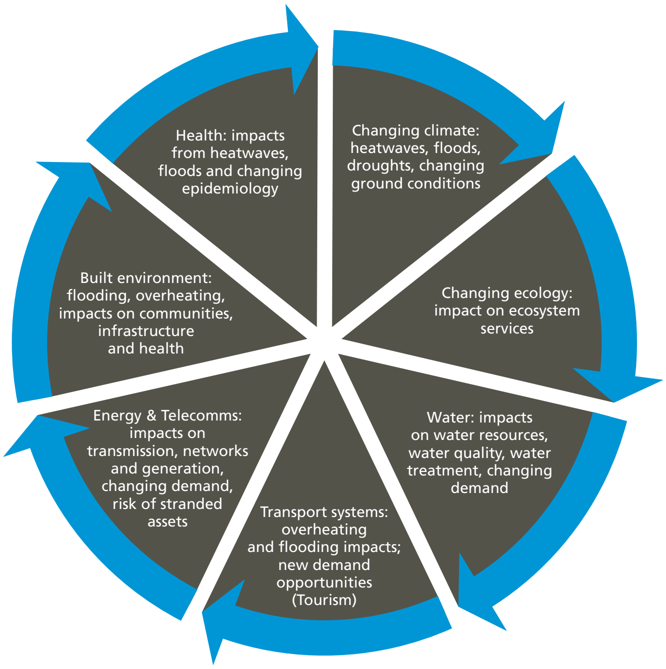


Figure 1.
Impacts of climate change on critical infrastructure systems

In a review published by the UK's Technology Strategy Board (TSB), titled "Design for future climate", the point is forcibly made that designers will need to rethink historic "rules of thumb", as we will no longer be able to rely solely on past experience but must take account of projections of future climate change, the principal source of such data in the UK being the UK Climate Projections (UKCP2009).

In order to improve the capacity and resilience of critical infrastructure to climate change, it is necessary to understand existing vulnerabilities, identify key climate change risks and reduce exposure to these risks. We can then develop capacity to cope with avoidable impacts, and incorporate sufficient flexibility into infrastructure to deal with changing climate risks over time.

It is clearly important that adaptation measures do not add unnecessarily to carbon emissions as this will then exacerbate the very problem being tackled. That is, the adaptation measures should themselves be (as far as possible) low carbon. For example, the TSB report indicates that passive approaches to building design that maximise comfort whilst minimising energy use can produce buildings that can maintain comfortable conditions well into this century. Moreover, dealing with more extreme precipitation events can include such straightforward measures as larger capacity building gutters, downpipes and drainage pipes. Sustainable urban drainage systems (SUDS) also have an important role to play. Other examples include using natural ecosystems to provide resilience (such as wetlands to ameliorate flooding risk), avoiding the over-engineering of defensive structures, the selection of materials with low whole-of-life carbon, and minimising project-related carbon through close attention across a range of areas from transport of materials to travel of personnel. Fundamentally, the approach must be one of designing out problems and, wherever possible, avoiding energy-intensive solutions such as high emission cooling technologies to condition poorly designed buildings.

Although adaptation and mitigation have generally been approached in isolation, without an understanding of both there is a real risk that actions taken to address one could actually make the other worse. Infrastructure planning will need to exploit the synergies between adaptation and mitigation policies to deliver resilience to a changing climate.

Understanding the risks to infrastructure systems within our natural environment and how they may change is crucial. New tools and approaches allow us to make more risk-based judgements around strategy and investment appraisal. Key to that will be consideration of whole-of-life of structures, evidenced-based assessment of policies and programmes in terms of energy (and hence carbon) and the vulnerability under future scenarios. As our critical infrastructure systems have typical life cycles of 50+ years, getting these decisions right is critical if we are to avoid locking-in carbon for future generations.

A high speed of change is critical

Since the last Industrial Revolution we have progressively taken longer and longer for big infrastructure projects to move from concept to delivery - unlike our Victorian civil engineering forebears who exhibited a sense of real urgency. Large infrastructure projects can take decades to be delivered. We must move faster as a profession; not only because the designs we create will form part of the low carbon economy but also because building codes and standards must be written as we go along. This will take considerable intellectual rigour on the behalf of the engineers and in particular their professional bodies.

2020 and 2050 may seem a long way off but with current lead-in times 2020 is now for medium-sized projects and 2050 is now for major projects. The major changes to infrastructure we make now will be with us for the next 50 years or more. To manage the carbon input to a project and to ensure the design takes account of inevitable climate change requires immediate action from the engineer. **My challenge to the engineer is - so what will you do on Monday?.**

Conclusion

The role of the engineer is clearly paramount. Due to the technical complexity of the issues facing us, the engineer will inevitably be the definer of the problem as well as the provider of the solution. We need to help our clients engage with the challenges of a low carbon economy and be clear in the provision of practical, affordable projects. So the performance specification ("The Question") must:

- Minimise the use of all resources required by all designs (based upon carbon budgets)
- Significantly improve the resource efficiency of construction /manufacturing operations
- Significantly reduce the use of operational carbon.

We must make carbon-intensive engineering socially unacceptable. We've achieved this with design from a health and safety perspective (although there is still much to do). The number of deaths in constructing the Great Western Railway would be totally unacceptable today.

You must be an engineer to change these things. Show ownership and leadership. Be bold and enhance the status of the engineer. There is an overriding need for engineers to show significant leadership that will build upon the reputation of the profession. A sense of pride and "I did that" will be central to deliver the necessary changes. Don't blame government, clients or the recession: in truth you are limited only by your ambition and ingenuity. Engineers have to demonstrate what is feasible so that governments and the financial community know where to go.

The challenges are deeply serious and the engineering community must make some fundamental changes in its professional behaviours: total, radical changes in behaviours that we have to call a revolution. Revolutions are uncomfortable and possibly prolonged. They are iterative and we will all make mistakes. Isambard Kingdom Brunel, after whom these lectures are named, made the occasional big mistake - but he was honest about them and learned from them, pressing on to greater things.

We are in the process of understanding the basic question of "where is the carbon and how do we de-carbonise?". As we develop our understanding of carbon-intensive design we can map activity against carbon budgets, prioritise and plan, and recognise how we might meet the incredibly tight timescales that face us. 2020 is now and 2050 is very, very close.

The international reach of the Institution of Civil Engineers (and the other professional bodies) provides a significant ability to share knowledge, improve skill and influence a broad audience. The challenges vary across the continents but many elements of the solutions are common and readily shared.

We must all promote action and a growing sense of engineering citizenship.

Summary

The drivers for change are clear and the initial framework for action is in place. Many nations have signed the Copenhagen Accord and have matched this agreement with national regulation to limit CO_2 emissions (or external energy supplies). In the UK we have the Climate Change Act and five-year CO_2e budgets to evaluate progress against massive reductions in fossil fuel usage by 2050.We are understanding progressively the strategic changes that must be made to our infrastructure and we have been intellectualising the idea of carbon critical design for two years or more. We must make a concerted effort to move beyond rhetoric.

- Firstly get your firm and your department to become truly carbon aware. Understand where the carbon is and focus on learning how to decarbonise your projects
- Develop and share tools to quantify and identify where savings can be made
- Be open and communicate with your professional colleagues, both locally and internationally
- Talk to the client. Offer a carbon saving and explain the logic
- Develop different skills and different resources.

Then iterate again, engaging more clients and with more refined carbon choices.

The conceptual stage is now akin to what Brunel would have experienced, little empirical knowledge, codes not becoming outdated continually, calculations rudimentary with many assumptions and a tremendous engineering challenge on your CAD screen.

The new design parameter (not having carbon) is indeed disruptive rather than additive.

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