Engineering for Climate Change-the adaptation challenge and the role for engineers

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Peter is a champion for developing global practice that demonstrates that the way we invest public and private money in the built environment could be made very much more effective if the public and private sector adopted sustainable development principles. He is a civil and structural engineer who has become a recognised world leader in major bridges (he received an OBE for successfully delivering

1. Introduction

In recent decades it has become clear that there can be no viable future for humanity without a healthy planet. Earth, water and air support the existence of an immensely complex living system, powered by the sun. We are part of this web of life and within a few generations we are using up most of the earth's stored fossil fuel resources. Their transfer from the earth to the atmosphere is significantly altering its composition. From our ever expanding urban centres, our tentacles now spread across the world. Our globalising economic system is destabilising the planet's life-support systems-the very systems that support us and the future of our children.

I aim to provide some innovative answers to the questions that flow from this:

Can we move towards a sustainable way of living?

What policies and investments are needed in low, middle and high income countries?

What is the role of the engineer in leading this transition to an Ecological Age?

I will start by examining the problems we are facing and then highlight the opportunities for change using examples of city retrofit and design of new urban settlements. I will show what we can do over the next 50 years and draw some firm conclusions about policies, changes, investments and the role of the engineer.

2. The transition to the Ecological Age

The earth spins round the sun and is a closed system. It receives energy from the sun and exports only energy into space. Photosynthesis in plants converts the sun's energy into carbon material which over human history has provided our primary energy source and has been the root of our food supply chain.

From 1700 The Industrial Revolution took civilisation from the Agricultural Age to the Industrial Age and into a resource dependent lifestyle in urban centres. There were voices of concern, even then, like economist Thomas Malthus(1) who argued that increases of population would at some point overwhelm our ability to feed ourselves.

But many of these predictions have proved to be wrong because of our extraordinary ability to increase food productivity using machines, higher yield plants, fertilisers and of course more fossil fuels. The population is now 7 times greater than when Malthus made his prediction.

We Civil and Structural Engineers are proud of the heritage of the profession's contribution to the rapid development of the economy during the industrial revolution. We stand on the shoulders of the great Victorian engineers who facilitated the rapid urbanisation of cities and helped to accelerate economic growth.

Industrial development and urbanisation have continued unabated since then using a similar model. Engineers have been at the heart of the design and delivery of the essential infrastructure for energy, water, waste, communications, transport, buildings and flood protection. Energy consumption is central to this model of human development and in designing and building these systems we have created the hard wiring of a non-renewable resource consuming society.

In 1998 WWF started publishing a biennial Planet Report (2) The 2006 Report showed that we are now living in severe ecological overshoot. We are now consuming 25% more resources than the planet can replace and are drawing down the stock of natural capital that supports our lives.

The key metric is the 'ecological footprint' of the population of each country. This is the area of earth surface required to support the population's lifestyle with water, energy, food and resources and waste absorption.

In 1900 we had an average of 8ha of land to support everyone's life on the planet, but today with population growth and loss of productive land from pollution we only have 2ha. We are living as if this hasn't happened and we are using between 3 and 5 planets worth of resources in the developed world.

China's president, Hu Jintao, in his speech at the 17th Party Congress in October last year, referred for the first time to 'moving China towards an ecological civilisation. He described this as using resources more efficiently, using renewable energy and living in harmony with nature'. China has realised that their industrial development model is rapidly becoming uneconomic because of environmental pollution and health costs and rising raw material costs.

My paper is about the start of the journey into the ecological age and away from this unsustainable direction. The paper uses the knowledge gained from our work all over the world and particularly the London Climate Change Action Plan and the design of eco-cities in China for our visionary client Shanghai Industrial Investment Company (SIIC).(3)

3. The Ecological Age Economic Model

If you imagine our current economic growth model as if it is living inside the Earth eco-system which supports our life you can imagine that as it grows bigger, some of that eco-system is being sacrificed. We have now realised that our global economy has become so big that the impact of the loss of the eco-system at each growth increment may cost us more than it is worth. Hence growth may be uneconomic and we may have to begin the search for an optimal scale in which marginal costs equal marginal benefits.

The critical task is to take human development forward with much fewer non-renewable resources.

We cannot move this way without valuing natural capital -solar energy, land, minerals and fossil fuels, water, living organisms and the services they provide. Once valued we can then make the right economic decisions to maintain their support.

The very long term objective is to reach a sustainable lifestyle that uses the energy from the sun. We need to find a soft transition over the longest possible period, so we can use fossil fuels and nuclear power as long as resources are available but with much less environmental pollution.

However in the shorter timescale we need to urgently reduce greenhouse gas emissions to the atmosphere by 80% from 1990 levels by 2050 in order to avoid catastrophic climate change according to the IPPC report.(4)

I will now look at the global actions being taken in high and low income countries to move in this direction.

4. Low carbon city living

A key question is whether we can take steps to reduce emissions without damaging our short term economic performance.

In high income countries like UK, Japan and USA we need to retrofit our cities and their power supply systems. Most detailed carbon emissions reduction studies like Stern (5) and McKinsey (6) say that the costs are within our means and will not hurt economic growth. For example the McKinsey report says that the US can reduce greenhouse gas emissions by one-third to a half by 2030 at manageable costs to the economy. Urban living now drives a high proportion of carbon emissions so I will focus on cities.

We are actually so wasteful, that there are many opportunities for rapid improvement. Each problem we have created in our development model tends to be addressed by another fossil fuel dependent fix and we have therefore created a stack of interdependent resource consuming technologies. In our work we have found that by resolving each of them in an appropriate way, the social, economic and environmental benefits achieved can be surprisingly large through what we call virtuous cycles of benefit.

The stacking of problems has led to a complexity of infrastructure with high maintenance costs and a clear vision is now emerging that the way forward is one of smart responsive simplicity rather than rigid complexity so life-cycle costs are much lower.

For example in a new compact mixed use development, people can easily go to work, school, shops and leisure facilities by walking, cycling or public transport .The residents save money, travel creates less pollution from car exhausts-this in turn leads to better health, lower social care costs and all this creates a more desirable place and a higher return for the developer.

The most liveable urban areas in the world like Vancouver are doing this and have one tenth of the freeways of less attractive North American cities and do not have the burden of their high maintenance costs. Waking cycling are preferred travel means with high quality public transport for longer journeys.

The space required for moving people in buses and on cycles is so much less than for cars, and then you don't need parking spaces. So reducing car use in city centres frees up a lot of valuable land for housing, parks and offices.

The overall aim is to move away from the Industrial model of cities in which power comes from inefficient centralised power stations outside urban areas, belching out pollutants; where products are consumed and thrown to waste in landfill; where fossil fuel based fertilisers are used to grow food and huge noisy freeways cut through city areas with hard landscape and fast water run-off.

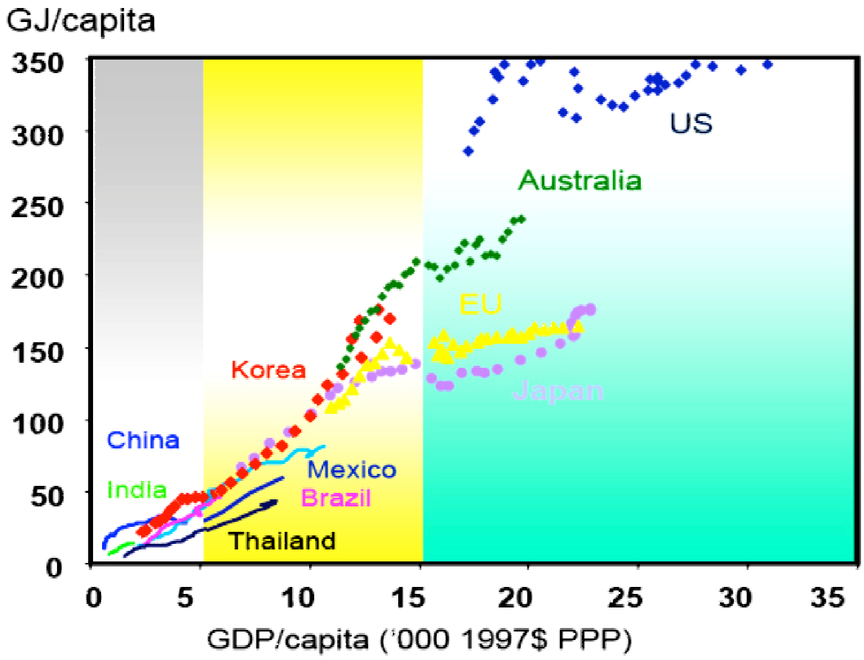


Figure 1:

In our industrial development model, energy consumption grows proportionately to GDP (Figure 1). Consumption eventually levels off as manufacturing is off-shored to low and middle income countries. The difference you can see in energy consumption now between USA and Europe is mostly car use in lower density sprawling urban US centres, so transport energy is a critical component of carbon reduction. In the ecological age model being pursued by China they are aiming to flatten their energy growth line by 20%. They intend to do this using the eco-city urbanisation model combined with building high speed rail lines and moving to energy efficient manufacturing.

It is critical to understand the importance of urban density for reducing transport energy demand. An average US urban dweller uses about 24 times more energy annually in private transport as a Chinese urban resident. (7)

You can see from the graph that there is a sweet spot of urban density of 35 to 100 people/hectare where public transport is viable and there is plenty of room for urban parks and gardens. So choosing the right density is really important in refashioning existing cities and building new ones.

4. London Climate Change Action Plan

In February 2007 London launched it's Climate Change Action plan (8) with the aim to reduce carbon emissions from primary energy sources by 60% from 1990 levels by 2025.This was in line with the 80% target by 2050.Without action London realised that emissions would rise by 30%, particularly driven by rising emissions from transport.

A decision was made to focus on the initiatives which would have the highest impact and create a shared agenda in which the public and private sectors and communities would work together to deliver change. 38% of emissions are created in homes, 33% in commercial premises, 22% in ground based transport (excluding air travel) and 7% in industrial production.

For homes and commercial premises half the reduction in emissions will come from changes to the energy supply efficiency and carbon content with a move to more efficient local power and heat/cooling grids from combined heat and power stations which use renewable energy sources such as waste biomass. Also the installation of energy from waste plants.

It was assumed that the national energy grid would move to a higher proportion of renewables.

The other half of the reduction will come from a retrofitting programme of improved insulation and more efficient lighting and appliances, combined with education for using energy more efficiently.

Also new construction aims towards zero carbon homes by 2016, but new build only contributes to 5% of the overall carbon reduction by 2025.

Transport emissions are made up of 50% from cars and motorcycles, 23% from road freight and the rest from public transport. Key initiatives for reducing emissions are:

- London wide road pricing with emissions banding to encourage low emission vehicles
- Introduction of more car clubs with low emission vehicles
- Investment in public transport to allow mode shifting
- Conversion of bus fleet to all-hybrid
- Improved energy efficiency of rail fleet and renewable energy supply contracts.

Introduction of freight consolidation centres with local green distribution fleets of electric vehicles.
Improvements in walking and cycling facilities

5. Eco-city developments in China

Figure 2: The Dongtan Eco-City Project

This site (Fig 2) with an area of 84 square kilometres, was chosen by the Beijing and Shanghai authorities because of the desire to develop Chongming Island, but at the same time to protect the adjacent wetland at Dongtan from future environmental damage. (Fig 3) The development is being facilitated by the construction of a major new road and rail link which will bring the site within a 40 minute travel time from the centre of Shanghai.

Figure 3: Wetland adjacent to Dongtan

Arup was appointed to carry out the planning of this new city by the developers Shanghai Industrial Investment Corporation in August 2005 with the aim to create a demonstrator of what China is calling a new paradigm of urban development and a first tentative step towards the ecological civilisation. A partnering agreement was signed in 10 Downing Street in November 2005(fig 4) to extend this approach to other cities across China and six other sites are now being planned in parallel using the same approach. Dongtan aims to provide a home and jobs for up to 500,000 people by 2030.

Figure 4:

The starting point for the work was a process of evolving, agreeing and defining sustainable development objectives for the project that would drive the master plan design and in particular the radical environmental performance.

Detailed analysis of the business and investment case for Dongtan quickly showed that China's new legal structures provide interesting opportunities for international companies to create public-private partnerships to deliver energy, water and waste infrastructure for sustainable cities in China. Also there are a many pension and hedge funds looking for good long term investments which are associated with infrastructure that drives a sustainable future. The Clean Development Mechanism provides opportunities to assist the financing of the renewable energy production facilities. So substantial innovation is likely to come from the financial community to drive change.

A key part of the overall management of the development is moving from planning to implementation through the creation of a performance specification for the whole 630ha start-up area, home to around 80,000 people. This innovative document enables both site-wide infrastructure and plot by plot regional developments to go ahead in accordance with the overall planning needs. The documents show how the sustainable development features fit with the current Chinese standards and codes of practice. They also enable the development to be phased in a way that optimises the business and investment case return. It is here that the more detailed issues of structures and choices of materials to drive ecological footprint were decided.

Environmental Protection of the Wetland

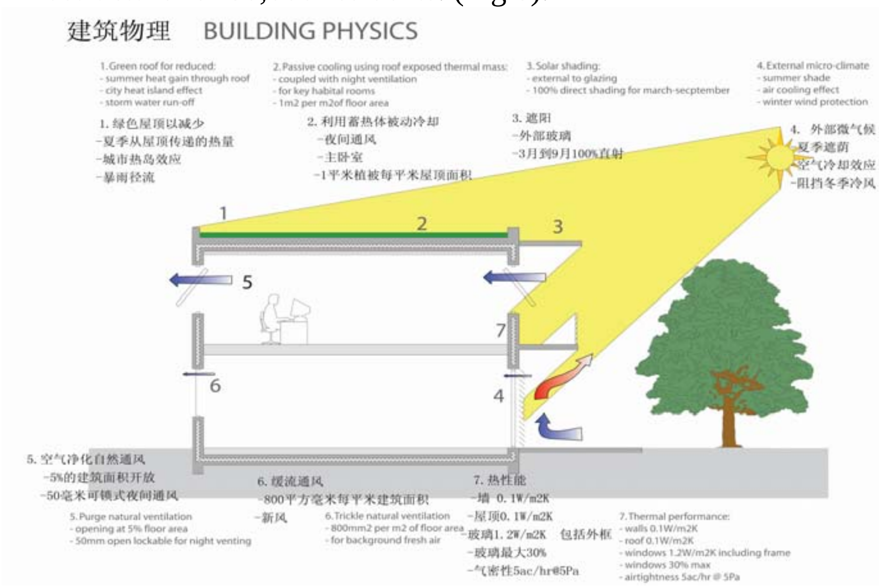
Figure 5: The City Development

The city development (Fig 5) will be separated from the wetland by a 3.7 km wide buffer zone, which will be an eco-park and wetland. No particulate emission vehicles will be allowed in the city so that air quality will not deteriorate. The battery powered, or hydrogen powered vehicles will be quiet and so birds will not be subjected to high noise levels. Light pollution will be avoided by facing the city away from the wetland. Water will be captured and recycled in the city so that current farm water run-off containing nitrates will be greatly reduced. No land filling of waste will take place on site as most waste will be recycled. Bio-diversity in the city will rise compared with the farmland as open water areas will increase, green roofs will attract more insects and urban parks will be planted with a rich diversity of plants and trees. There will be green corridors through the city as well. (Fig 6)

Figure 6:

Social and Economic Benefits
Business as usual would be a single use housing estate on the 630 ha site for around 50,000 people and creating around 19,000 jobs. The eco-city approach has 80,000 residents and 51,000 jobs, which means everyone who can work should find a job locally. Mixed use development means that jobs are close by and also social and retail services are clustered near three village centres. The developer is able to build twice as much floor space to sell than in the business as usual case and the place is more vibrant, healthier and attractive to live in.

Energy
The development runs totally on renewable energy. In order to do this the buildings will be designed so that energy demand will go down by 64% compared with normal Shanghai practice. (Fig 7) Renewable energy will be produced using a combined heat and power plant fuelled by rice husks, large and small scale wind turbines, photo-voltaic panels on buildings and energy from the waste stream. Total reduction in carbon dioxide emissions is 350,000 tonnes per annum for buildings and infrastructure for 80,000 residents. (Fig 8).



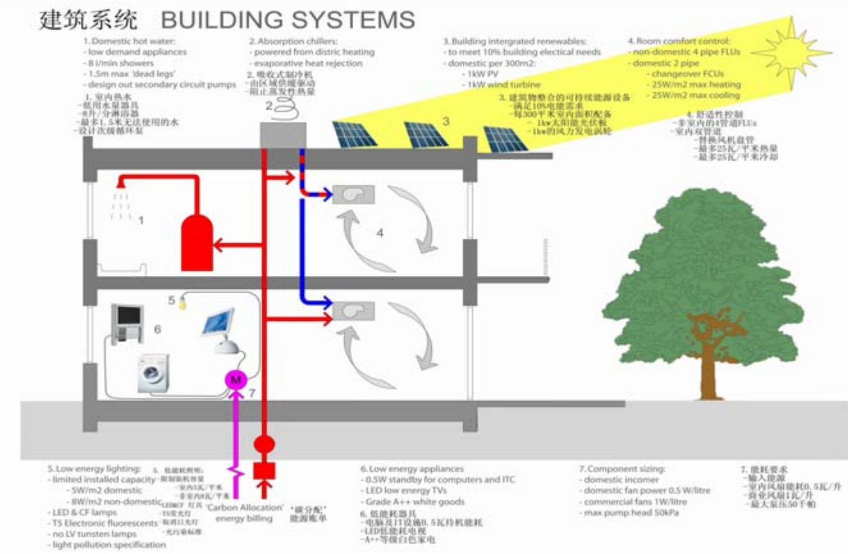


Figure 7:

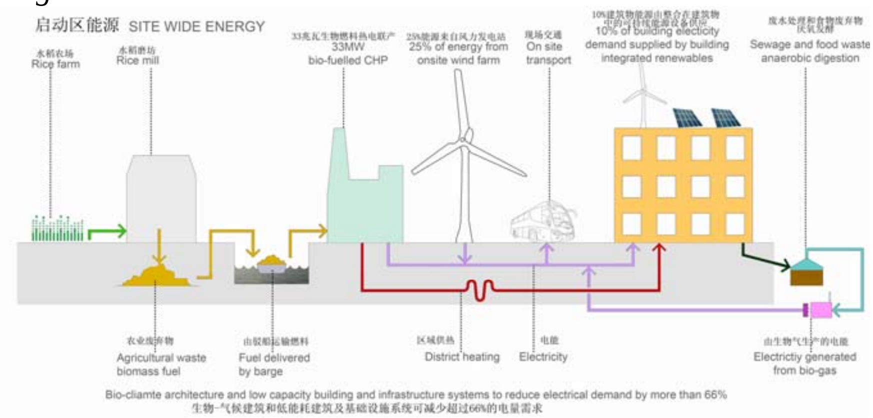


Figure 8:

Water

Potable water derived from primary treatment and grey water, recycled within the city, will come from water stored in ponds and lakes and from the canal system on Chongming Island. (Fig 9) Separation of potable water and good appliance design will enable consumption to be reduced and wastewater recycling will enable discharge from site to be reduced by 88% compared to normal site practice.

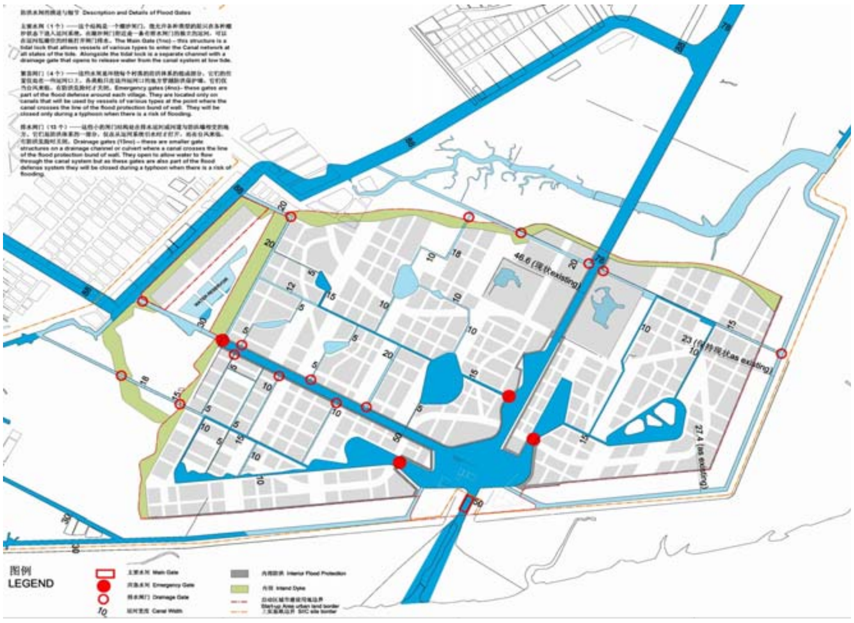


Figure 9

Waste

All waste will be collected and most recycled into useful resources. For example, rice husk ash from the CHP plant will be used to make building panels. Also energy will be derived from biomass waste and minerals will be extracted and recycled into agricultural production.

Transport

Good public transport in the form of a bus/tram route and a water taxi service on the canals will be available within 550 metres walking distance of all residential and commercial accommodation and real time information will encourage use. A walking and cycling grid will cross the city and provide easy access for all, including disabled people. These routes will pass through the parks and go alongside the canals.(Fig 10) Thus the use of cars will be discouraged and car trips will be shorter and fewer. Goods will all be delivered to a consolidation centre on the edge of the city from where they will be delivered street by street using zero emission vehicles, rickshaws and water craft. All vehicle power will come from renewables and so there is a further reduction of 400,000 tonnes of carbon dioxide per annum, compared to business as usual.

Figure 10:

Ecological Footprint
The estimated ecological footprint for life in the Dongtan start-up area is 2.6 ha per person compared to nearly 7ha in the centre of Shanghai. The global earthshare is currently around 1.8ha per person. (Fig 11)

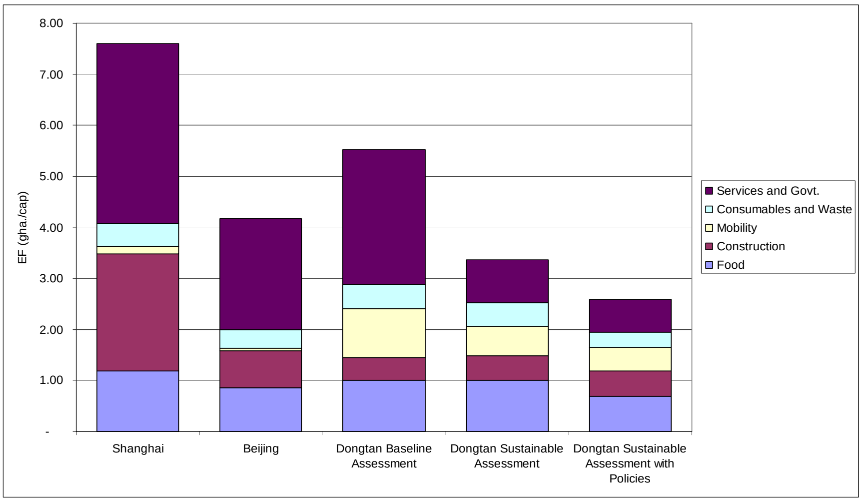


Figure 11:

Agricultural Production
Research is underway into the viability of creating food production capacity in the city which is as great as that on the farmland on which the city is built. This will take place in food production buildings in which high quality green vegetables are grown.

Flood Protection
Space is allowed behind the main sea wall to enable it to be raised in the future if sea level rise takes place. Also, a secondary cellular protection system is provided within the city for protection against extreme overtopping events caused by surges or tsunamis.

The Wanzhuang Eco-City project

The site of Wanzhuang eco-city is in China's Hebei Province, 45 kilometers south east of Beijing and halfway between the nation's capital and the port city of Tianjin. It is close to the city of Langfang which some have dubbed 'China's Silicon Valley' due to its fast developing economy based on computing and technology. The 80km² site includes 15 villages with a total population of 100,000. The area has been selected by the Chinese Government for development into a city that will accommodate a population of 400,000 people by 2025.

Prior to Arup and SIIC's involvement, the plan for the city was a Los Angeles-style grid of roads based on SuperBlocks – gated communities on a mammoth scale, typically over one kilometer square, that cause social segregation, encourage car use and rely on centralised services – electric power lines, sewage treatment plants, sewers and sanitary water supply. The design swallowed the existing villages and would have relied on private cars for transport.

Arup's masterplan is very different. The design proposal begins with the simple proposition of retaining and enhancing the existing communities through selective renovation and regeneration. Historic buildings and street patterns are retained as a footprint for the new city and the villages expanded as mixed–use communities which connect with walking, cycling and public transport to create the city. Jobs will be created for residents in a range of different zones. Expansive historic pear orchards, which are a key feature of the region, will also be preserved.

Arup proposed that the standard of living and environmental quality of the existing villages should be improved, as well as the opportunities for village communities through education and jobs. A community consultation was carried out with villagers to ensure that the project priorities of addressing culture, water transport and green space, were correct.

Culture

The existing villages in the Wanzhuang area are culturally diverse and under the Arup scheme will become distinct neighbourhoods.

Before finalizing the masterplan, Arup ran a workshop with village leaders in order to make sure they had the objectives correct from the start.

This led to a cultural workshop with villagers where they expressed the type of cultural spaces they would like within Wanzhuang, for example, areas for 'pole walking' and public squares for dancing.

The aim of these consultations is to encourage local identity and ownership, as well as promote stakeholder engagement in community decisions. This includes developing social equity that embraces the celebration of culture and civic pride.

Water

Water scarcity is a concern in neighbouring Langfang, therefore a range of methods for reclaiming and distributing water for drinking and non-drinking (grey water) use in Wanzhuang have been put forward.

Drinking water will be harnessed from underground reserves, and non-potable water will be made available through the treatment and recycling of alternative sources of water. This water will also be used to recharge the underground reserves.

By recycling all the existing waste water from the area and recycling it as grey water, there will be enough water to irrigate the farmland for the first time. This, in turn, will increase food yield.

Reintroducing techniques from the past, slopes which cause erosion and water run-off will be replaced by terracing. The flat surfaces contain and soak away rainfall.

Water will be harnessed in the existing canal network, but significant improvements have to be made to the currently polluted network.

A new water and waste management system will be incorporated with the canal network, including new pedestrian paths for improved access and tree planting schemes to improve shading and reduce water evaporation.

Transport

The site is intersected by an existing freight and passenger railway linking Beijing and Tianjin.

The Government has proposed a new high-speed rail link that passes through adjacent LangFang.

A new public bus or tram network linking all the villages to Langfang and to the new high-speed rail station has been proposed.

A network of direct paths will connect the villages to encourage walking and cycling and the city centre will be a dedicated pedestrian zone.

Cars will have to follow protracted routes along the canals in order to avoid the pear orchards and the cycling and pedestrian paths.

Fossil fuel vehicles will be restricted and a programme of extending the use of cleaner vehicle technologies will be promoted.

Social infrastructure such as schools, offices, medical centres and shops will be spread throughout the city to reduce the need to travel and minimise use of private cars.

Green Space

Historic pear orchards and poplar forests will be retained and enhanced to become an expansive city park stretching all the way to Langfang town centre.

The new park defines the limits of each development area around the villages and reinforces the city edges with high density development.

The city parks will provide additional visual and physical amenity to residents living along its edges, therefore increasing its value.

6. Policy and practice for engineering the Ecological Age

It can be concluded that in high income countries the following infrastructure investments and approaches are needed to retrofit existing urban and rural developments. In low and middle income countries, such as China, these are the systems with which to develop new urban-rural developments:

Transport:

Efficient, comfortable zero emissions mass transport..

Walking and cycling routes.

Intercity high speed rail passing through international airports.

Green logistics services from freight hubs.

Water and Waste:

Water capture, storage, recycling and separate potable and grey water mains.

Waste collection, recycling and anaerobic digestion.

Fitting of separating toilets and vacuum collection of solid waste.

Mining of construction materials from cities.

Energy:

Large scale renewable energy, including desert solar power.
City combined heat and power and local heat and power grids.
Carbon capture at power stations.
Use of secondary biomass for energy and products.

Food and communication:

Intensive food production in cities.
Broad band communications and tailored information.

All of these systems are connected and form virtuous cycles that integrate the environmental, economic and social performance of different components of built environment so that change in the design of one can lead to benefits in another.

The following urban design principles are also important in making places sustainable:

Adopting Smart, responsive simplicity rather than rigid complexity. This means dismantling the layered complexity of fossil fuel powered systems of the industrial age and using clean, flexible. adaptable and renewable systems to support life.
Setting Sustainable development framework objectives and targets at a regional and local level to drive investments to meet ecological age principles.
Creating regional and local *Land use plans.* There are many advantages in this of compact mixed use development with high density, especially around public transport nodes.
Closing the resource flow loops for water, energy, waste and minerals between rural and urban systems.
Combining adaptation and mitigation to climate change.

Sustainable urban design principles need to be supported with smart and available developing technologies such as:

LED lighting
Electric and hydrogen fuelled transport.
Anaerobic digestion of waste.
Intensive food production using hydroponics and nutrient feed.
Secondary biomass fuels for air travel

There are three policy areas which will support the changes needed.

First, policies which drive towards the sustainable or optimal scale of the global economy-these need to address the limiting of scale and the fact that previously free natural resources and services have to be declared scarce economic goods. Once they are scarce they become valuable assets and the question of who owns them arises and therefore the issue of distribution must be addressed, for example:

Energy feed-in legislation.
Polluter pays taxes introduced progressively, with proceeds used to drive public sector investments which help the private sector.

Tradable permits with quotas set so that the marginal social and business costs are equal to the societal benefits.

Second as sustainability is the criterion for scale, justice is the criterion for distribution to ensure that there is fairness across society and globally, for example:

National and regional land use plans.

Land value taxation to redistribute value to the community.

Bartering of human development benefits against environmental clean up benefits.

Contract and Convergence for carbon and Shrink and Share for ecological footprint.

Thirdly, policy needs to ensure that allocation of resources are as efficient and cost effective as possible, for example:

National resource efficiency targets and circular economy laws to incentivise symbiotic manufacture.

National policy to manage the rebound effect of improved resource efficiency.

Radical transformation of the infrastructure that supports life on the planet is needed if we are to attain a sustainable future. This requires strong partnerships between public, private, NGO and community groups within national communities and global cooperation, but with existing technology.

Engineers have global experience, are adept at multidisciplinary team working, which will be essential for success and can design and deliver these new infrastructure systems. However we recognise that resource levels are limited to undertake such an unprecedented challenge in a very urgent timescale of no more than 50 years and so we need to train and motivate young people to join this challenge and be the engineering stars of the 21st Century.

A global network of sustainability institutes is being created to help speed up knowledge sharing and delivery capacity and a delivery model of using public, private partnerships with NGO's and community groups is proposed for retrofitting.

This is a first glimpse of a way forward and a credible vision of the future but it is only a modest start for a long journey. The aim is that the Copenhagen Climate Summit in December 2009 will be the moment the world gets together and agrees that we really know enough and are prepared about the direction that we need to take.

It is hoped that the global community of engineers will come together and inspire young people to join us in this challenge, almost certainly the greatest humankind has ever faced.

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