Conference paper

Sustainable building construction for structural engineers

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Introduction

There is a good deal of confusion about what constitutes sustainable construction, and many sweeping claims for buildings, products, and even materials purporting to be 'sustainable'. In reality such things are neither sustainable nor unsustainable in themselves. However, used in an appropriate way they can contribute to a sustainable community, society, or way of life. Sustainable construction can be considered as a subset of this broader sustainable development in which economic growth and social progress for all is coupled with effective protection of the environment and prudent use of resources.

There are many definitions but one of the easiest ways to understand sustainability is to consider the legacy that we leave. Whether through environmental pollution, depletion of non-renewable resources or social inequity, we need to recognise the impacts of our actions on others, and the rightful aspirations of those who currently enjoy living standards lower than our own. It has been estimated that three planet Earths would be required to support the current world population at a standard of living equal to that of the UK!

What does this mean? In striving for sustainable development we are looking to continue our economic progress, and to do so without impeding similar progress in other parts of the world (indeed there is a case for encouraging this) without damaging our natural environment (again it could be argued that we should be striving to improve this, because of the damage which has been done in the past) recognising the needs of the whole of society

There is a growing recognition of the importance of this, and many governments are signing up to agreements committing to significant improvements, for example in reduced carbon dioxide emissions. However there is also an understanding that measures must be affordable and this has introduced the consideration of economics in addition to those associated with environmental and social issues. Some commercial organisations are also recognising that there are business advantages in adopting sustainable principles in their operations.

What is sustainable construction?

Construction has been identified as being particularly important because of the significant environmental and social impacts which the built environment has on everyone's quality of life. It is estimated that, on average, we spend 90% of our lives in buildings. Whether at home, at work, in education or at leisure, everyone uses, and indeed relies on, the outputs from the construction industry. Furthermore, people's performance and productivity can be enhanced by improving the quality of the buildings in which we live and work.

But the negative impacts are also significant. Each year in the UK the construction sector consumes over 420Mt of a wide range of raw materials, including aggregates, and generates about 94Mt of waste – approximately 13Mt of which is estimated to be due to over specification. The energy associated with servicing buildings also accounts for approximately 50% of all energy used.

Some might argue that construction of any form is an artificial intervention and therefore harmful, but most would recognise the need for buildings, bridges, and other structures – and recognise that we would be a poorer society without such structures. The challenge is therefore to consider these broad questions at a detailed level, against the generally accepted measures of societal impact, financial cost-benefit, resource use (during construction and in service), the effects on global warming and climate change, pollution, and the legacy – what remains (good or bad) at the end of life.

The main issues for construction when considering sustainability are what to build, where to build, how to build, and whether to build? And these relate to planning (what, where and whether to build) design (ensuring that buildings make a positive contribution to occupants and others, and that their consumption of resources, particularly in service, is as low as possible) construction (ensuring that material consumption, particularly of critical resources, is minimised, and that disturbance during the building process itself is minimised – how to build).

Inevitably there are often conflicts with specific actions providing benefits when measured against certain indicators but having a detrimental impact when measured against others. It is therefore essential to consider an holistic approach and to take account of long term implications using a life cycle assessment.

Iron ore extraction – The construction industry consumes a huge volume of raw materials and the extraction processes can be damaging to the local environment

The decision on 'What to build?' relates more to social and economic considerations than engineering, but the structural engineer should nevertheless be aware of the issues. For example, in the UK the most pressing need is currently for housing with approximately 4M new homes needed over the next 15 years.

The question 'Where to build?' is also associated largely with social and economic issues, but there will almost certainly be implications for the structural engineer. In the UK we have limited land, and in the recent past we have seen cities decay or become so dominated by commerce that they became ghost towns at night. There has therefore been considerable emphasis given to redeveloping waste or brownfield sites, and constructing residential accommodation in the heart of cities. The location of buildings also has a significant impact on travel distances, and as transport is another major consumer of energy some priority has been given to reducing travel distances and encouraging the use of public transport, for example by locating buildings close to bus and rail routes.

Waste ground – locating new buildings on brownfield sites makes best use of a low quality resource and avoids potential ecological damage to greenfield areas

How to build

This is the probably the most important question for the structural engineer, and the one we can have most direct influence. The impacts are more environmental than social or economic, although these should not be ignored, and both construction and occupation need to be considered. The most important issues relate to the construction materials used, the control of waste during construction, and construction processes which are sensitive to the community and the environment.

Materials for construction

Clearly how materials are sourced and processed is very important. For steel this includes the extraction of iron ore, through the processing and transportation, to its final use, and subsequent re-use, or recycling through the scrap route. For concrete there is again the issue of sourcing the raw materials – aggregates, and limestone (for cement) in particular. In the UK suitable sources are limited and often in areas of outstanding natural beauty so extraction can be very detrimental. Furthermore cement manufacture accounts for approximately 2% of UK carbon dioxide emissions. There is therefore much interest in using recycled materials and cement replacements. A small number of projects have been developed using recycled aggregate concrete but difficulties associated with the supply of suitable material for reprocessing, inevitable reductions in quality, and lack of detailed guidance currently discourage widespread implementation. However, specifying cement replacements such as pulverised blast furnace slag is something which can be seriously considered on almost any project.

Timber is often cited as the ultimate sustainable material. However, as with all materials, the precise nature of the sourcing of the timber is very important. In general softwood from a local, managed estate is likely to have good credentials, but hardwoods imported from overseas and harvested by clearing large areas of rain forest is not.

In the UK the suppliers of construction materials generally take these issues very seriously and produce regular reports on their environmental performance. Some may be less careful, although the products may be cheaper. Specifiers therefore have a responsibility to take account of how producers deal with their environmental responsibilities as well as the price they charge for their products.

Structural engineering design is generally concerned with efficient (but not necessarily optimum) use of materials for the structure. However, a global approach is generally more appropriate, looking at all materials and not just those associated with the structure. Thus using a less efficient but shallower floor structure could reduce the overall building height and consequently the materials needed for cladding.

Another area in which significant progress has been made is in relation to fire protection, particularly for steel framed buildings. The fact that the strength of steel reduces rapidly under fire conditions has traditionally meant that some form of insulating material has had to be applied to the steelwork. This fire protection is both costly and time-consuming as it generally has to be performed on site. Recent research has shown that in many circumstances it is possible to leave a significant number of steel beams unprotected, and possibly to use intumescent paint protection for the remaining beams. If the paint can be applied off-site, a complete activity is removed from site, offering significant savings in construction time and efficiency.

Steel piles – there is increasing interest in reusing components, including steel piles. This not only reduces the need for new products but also leaves the original site clear from the 'pollution' of permanent foundations

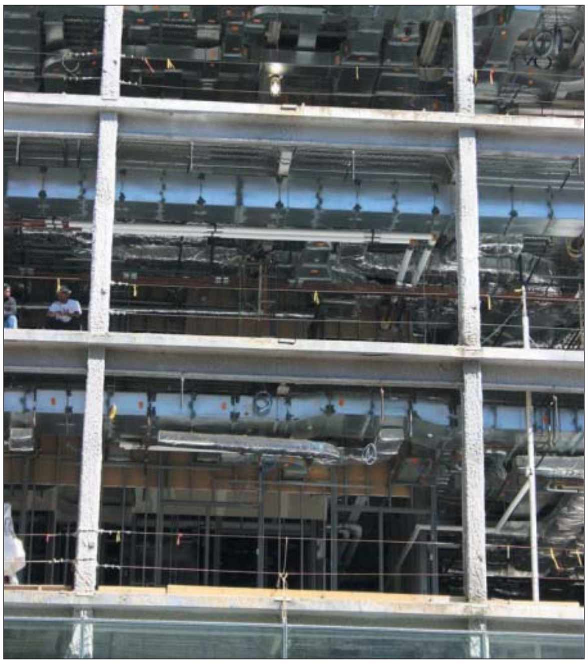
Scrap metal yard – some materials, such as steel, are readily recycled, and there exists an established infrastructure to achieve this

One common measure of the environmental credentials of a material is its embodied energy – that is the energy associated with extracting raw materials, transportation and processing – typically expressed in GJ/T. However care is needed when comparing different materials based on quoted values for embodied energy. One reason for this is that much lower tonnages are generally required for high strength materials for the same function – steel has a much higher embodied energy per tonne than concrete but a steel beam is much lighter than the reinforced concrete equivalent. Another problem is that generic values do not necessarily represent actual production impacts. For example, the embodied energy of aggregates depends heavily on transport distances, and different production processes can use vastly different amounts and types of energy.

Another difficulty is how to allow for recycled content. Steel from a process which uses 100% scrap as its source has approximately one third of the embodied energy of steel from virgin ore. However, there is an inadequate supply of scrap steel, despite the fact that a very high proportion of steel is recycled as scrap rather than sent to waste. Some virgin steel production is therefore essential, and this steel will, in turn, be recycled for further use at some time in the future. It would therefore seem reasonable that a composite figure should be used but at present there is no clear method agreed for determining its value. The case of concrete which uses waste products (fuel ash or blast furnace slag) as a cement replacement is similar – how should the embodied energy of the replacement material be accounted? Not surprisingly, the steel and concrete industries have been exercised about how this benefit should be counted in relation to the impacts associated with their products, although for the structural engineer the important point is to use such replacements where possible.

In practice these problems are of little significance as studies have shown that, for most common building types, there is very little variation in the embodied energy of a building structure regardless of the structural system used. This is further emphasised by the fact that the embodied energy of fixtures, fittings and finishes, is much higher than that of the structure for most building types, and that over the life of the building these will often be renewed, contributing yet more embodied energy. In general the embodied energy associated with the structure is simply that of the initial construction. Of even more significance is the operational energy over the life of the building which often greatly exceeds total embodied energy. For some structures such as bridges, however, operational energy is not a consideration, and embodied energy is therefore much more important. Similarly, as buildings become more energy efficient in their operation, so the balance will change.

In summary, good sustainable construction practice for the structural engineer with regard to materials is to use minimum quantities consistent with performance requirements, use recycled or recyclable materials where possible, and source from sustainable supplies. In all of this it is important to take an holistic view and consider implications beyond just the structure and the initial construction stage. This is therefore nothing more than what might be regarded as good engineering practice.



Many buildings are highly serviced and the integration of the services, the ease with which they can be replaced, and most importantly the efficiency with which they operate, are crucial issues in achieving sustainable construction

The construction process

The main issues concerning the construction process are reducing waste and minimising the impact on the local community. The construction industry produces an alarming quantity of waste, partly as a result of demolition, and partly because of excess supplies to site. Careful planning at the early stage of design can help to minimise waste by recycling and avoiding over-specification. If demolition of existing buildings is part of the construction sequence, selected materials can be sorted for re-use or recycling. This can include bulk materials such as masonry and concrete which may have no potential for high grade re-use but which can often be used as fill on site rather than taking away to landfill. In some cases they may indeed have a higher re-use value and this should not be ignored.

Waste from the construction process itself needs careful management, but again it is possible to minimise quantities taken from site to landfill by segregation and appropriate treatment – for example timber, paper and cardboard can be composted and added to the topsoil. These simple practices not only minimise landfill but also save money.

One of the most effective ways of reducing the impact of construction on the local community is to make maximum use of prefabrication. This minimises site activity and can provide efficient, safe, fast construction. Duration and intensity of disruption and annoyance are both reduced as more work is conducted off-site, and at the same time quality is often improved.

Energy efficiency

Energy consumption is a major concern and one which is likely to increase rapidly as pressure on diminishing reserves of fossil fuels increases. Buildings are major consumers of energy, and much research has been done into both reducing energy consumption during the normal use of buildings, and also how to generate power from renewable sources.

How to reduce energy consumption has to be related to particular building use. For example, even in the UK's climate, commercial buildings now need cooling rather than heating for most of the year. There are various contributors to this – for example heat emissions from office equipment, solar gain, occupancy levels, and sealed environments. For this type of building natural cooling systems are beginning to be incorporated as part of the design. These generally use exposed parts of the building's structure – typically the underside of the floor slab – to absorb heat during the day and release it to the atmosphere during the cooler night. Some notable buildings have successfully incorporated this principle, although it is recognised that such natural cooling may only moderate temperatures by a few degrees.

Artificial lighting also accounts for a surprisingly high proportion of energy consumption. By providing good levels of natural light, energy consumption can therefore be reduced, but the key is to do this without glare or solar gain. Orientation and siting of buildings are therefore very important, and suitable external shading is also generally needed. In addition to energy savings, natural lighting improves the interior environment, and there is evidence to show that this can increase productivity and reduce absenteeism.

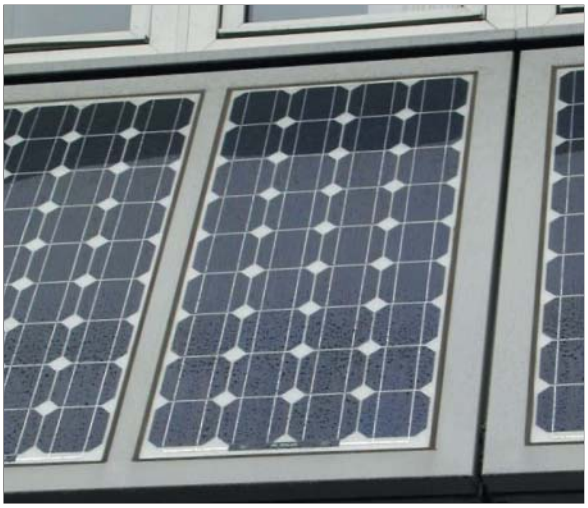
For residential construction the concern is generally to retain heat during the winter months (although sales of domestic air conditioning systems are on the increase). The issues here are therefore a well sealed and insulated envelope. The government has set ambitious targets to reduce emissions of carbon dioxide and indirectly our burning of fossil fuels. One way in which it intends to encourage this is in setting much more stringent targets for the air-tightness of buildings and their thermal insulation. Insulated panels are already widely used, but air-tight construction is much more difficult. In particular the joins between individual elements of the façade, and at details such as doors and windows, are very difficult to seal effectively. However as more and more construction is becoming system-based, it is quite feasible to imagine a self-sealing cladding system based on gaskets at these critical junctions. Together with high levels of insulation this could make a major improvement in energy efficiency and hence reduce carbon dioxide emissions.

In all of these cases there is often benefit to be gained environmentally, socially and economically. Reducing energy consumption is certainly beneficial in terms of environmental impacts and operational costs, and improved natural lighting and temperature control improves the well-being of the occupants. This might, but not always, be at the expense of increased capital costs – in some cases reduced energy demands also mean reduced plant and services with consequent reductions in capital cost as well.

Alternative energy sources such as photovoltaic cells, solar panels, and wind turbines are increasing. Photovoltaic cells have been used on a small number of buildings and their cost-effectiveness is improving. They are traditionally attached to a glazed surface, but in principle it seems logical that they should be inte-

Rubbish skip – a large quantity of new material delivered to sites is not used and scrapped. Careful specification and husbandry of resources can minimise this waste. Segregation of unavoidable waste will help facilitate its reuse

Good levels of natural lighting, yet avoiding glare and solar gain, not only reduces energy consumption but also provides a better internal ambience and a more productive environment



Photovoltaic cells are still developing but can make a useful contribution to the power needs of a building as here in the University of Northumbria

grated into the surface of the normal cladding system. This might pose some interesting challenges for manufacturers of sheet cladding systems but the benefits could be enormous. Wind farms often raise fierce local objections, but small installations servicing individual buildings are much less obtrusive, even if they do need to be supplemented by electricity from the grid at peak demand.

Whether to build?

Refurbishment of an existing building is often considered as an alternative to new construction. The potential benefit – or otherwise - of this can be difficult to determine, despite the fact that the use of raw materials would appear to be significantly lower. In fact considerable construction work and materials may be required, particularly if a building is to be re-structured. However if an existing structure is generally sound and suitable for its new purpose, it may be sufficient to over-clad and/or over-roof, improving the appearance and significantly reducing energy consumption.

Allied to this it is good practice to design buildings for future flexibility to avoid premature replacement. Such buildings are characterised by long span beams providing wide open column free spaces which can be used in a variety of configurations. Buildings should also be designed and constructed for durability, again to minimise the need for replacement.

The ideal strategy at the end of a building's life is to re-use, if not the building as a whole then at least the individual components. At present the reclaiming of structural components, such as beams and columns, for further use is very limited. This is partly because of the difficulties of dismantling and separating the structural components, and partly because a prospective buyer needs to know something of the history and specification of the second hand material. The first of these issues is being addressed by a number of researchers, but it is clear that a fully dry form of construction would be much easier to dismantle (rather than demolish) than one which used, for example, *in situ* concrete floors. The issue of identification and history could be dealt with by incorporating some marking on the components, but it must be remembered that the life span of a building is normally several decades, and conventional markings could be damaged during this time. An alternative, arguably more reliable, approach would be to incorporate some intelligence into the component itself – creating a so-called smart material.

Lifecycle assessments

Even this brief overview highlights the complex interacting issues involved in considering sustainable construction. Many of these are qualitative rather than quantifiable, and it can be very difficult to develop detailed methods which will inevitably lead to sustainable solutions. However, simply by considering sustainability as an important goal is a major advance. Even in the case of a single impact such as energy consumption there are interactions – between embodied and operational energy – and what is important is that the whole building is considered over its full life cycle. This is an unfamiliar and complex process for most building designers, and commercial software is being developed for use in this field. Such computer based design aids include assessment tools which 'score' a building against a range of potential impacts, and as the government starts to develop a code of practice for sustainable buildings it is likely that such assessments will become integrated into the design process.

Current trends

The principal drivers for sustainable construction, led mainly by the government, are legislation, fiscal measures, and consensus. Recent changes in the Building Regulations have reflected some of the points raised above, and a new, voluntary Code for Sustainable Buildings is under development. Many of the government actions are being developed in concert with the industry rather than imposed from above, and this should encourage participation and acceptance. However, one of the main impediments relates to ownership and responsibility for sustainable construction, and this is magnified as a result of the complexity of the construction industry and the long supply chains.

The developing Code for Sustainable Buildings is possibly one of the most important initiatives currently in progress. The intent is that it should be voluntary, with an initial focus on building process, with a requirement to incorporate a minimum percentage of recycled products or materials, and performance related to water, energy and resource use. Site specific issues will be ignored, but serviceability issues such as durability and flexibility, and occupant well being (air quality, natural light, acoustics) will be included.

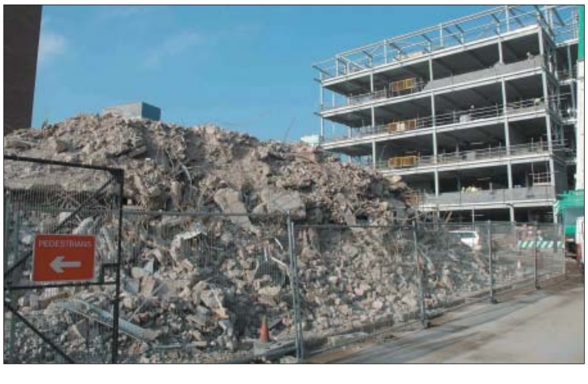
It will be based on an holistic quantitative assessment with simple compliance criteria and a reasonable compliance process. It is anticipated that CSB compliant buildings will be characterised by being of higher quality and having reduced running costs; they should therefore be more marketable

Conclusions

There are no prescriptive methods which can be adopted for ensuring sustainable development. Instead it is important to understand what sustainable development means to you and your clients, and to use whole life thinking and high quality information to inform your decision-making. It is generally operational environmental impacts which have the greatest effect and as a priority, the design should seek to minimise these. Where possible, consideration should be given to extending the life of buildings by renovation and refurbishment, and associated with this, designing for flexibility to extend building lifetimes and for demountability to encourage future reuse and recycling of products and materials.

The construction industry is characterised by long supply chains, and it is therefore important to engage with other organisations about the goal of sustainable development. This can mean, for example, selecting responsible contractors who have embraced sustainable development principles, rather than simply accepting the lowest price.

In the UK there is a growing recognition of the importance of sustainability, and government is taking its responsibilities very seriously. We are therefore beginning to see more projects designed to address this, increasing incentives and penalties, and more support through design data and software tools. Structural engineers should certainly be aware of the broad principles of sustainable construction, and have an important part to play in what must be treated as a multi-disciplinary, integrated treatment of the issues.



Demolition waste – Demolition of buildings at their end of life is wasteful of resources and creates a heavy demand on landfill. Ideally materials and components will be reused to minimise these impacts