The potential impact of climate change and global warming is without doubt one of the most life-threatening challenges facing humanity. Central to this challenge is our dependence on fossil fuels as the primary source of energy – the major contributors of greenhouse gases (GHGs) including carbon dioxide (CO₂) – and the extensive use of non-renewable resources.

It is now widely recognised that our climate systems are warming: there is also fairly good evidence that other effects of regional climate change on natural and human environments are emerging, although many are difficult to identify due to adaptation and non-climatic drivers. Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. [1]

Anthropogenic warming have some some impacts that are abrupt or irreversible, including severe species loss, depending upon the rate and magnitude of climate change (fig. 1).

Nevertheless, a wide range of adaptation options is available, although a more progressive rate of adaptation than is currently evident is required. With an increase in adaptation rates, many impacts can be reduced, delayed or avoided. [3] There is thus a causal relationship between climate change mitigation and sustainable development: Sustainable development can reduce vulnerability to climate change by enhancing adaptive capacity and increasing resilience.

The construction and maintenance of the built environment has a fundamental role to play in this challenge, as energy efficiency options for new and existing buildings could considerably reduce CO₂ emissions. By 2030, about 30% of the projected GHG emissions in the building sector could be avoided while simultaneously improving indoor and outdoor air quality, social wellbeing and energy security (fig. 2).

At the same time, the built environment is where the majority of the world’s population now reside: one in every two people lives in a city. [5] Global population has expanded more than six fold since 1800 and gross world product more than 58-fold since 1820. As a result, the ecological footprint (EF) of humanity exceeds the earth’s capacity by about 30%. If we continued on the same development trajectory, by the early 2030s, two planets would be required to keep up with humanity’s demand for goods and services.

Sustainable development imperatives

However, while the contemporary focus on energy efficiency, conservation and alternative energy sources is entirely appropriate, it is important not to forget the implementation of other sustainable development imperatives, which calls for the use of complementary approaches.

The notion of sustainable development arose out of the seminal study commissioned by the United Nations. This report, Our Common Future, also known as the Brundtland Report, coined the phrase “sustainable development” and its definition “those paths of social, economic and political progress that meet the needs of the present without compromising the ability of future generations to meet their own needs”. [6]

The 1992 Earth Summit in Rio challenged humanity to reduce its impact on the earth. At this summit the assembled leaders signed a Statement of Principles on Forests (to guide the management, conservation and sustainable development of all types of forest); the Framework Convention on Climate Change (an agreement between countries for action to reduce the risks of global warming by limiting the emission of greenhouse gases); and a Framework Convention on Biological Diversity (an agreement on how to protect the diversity of species and habitats in the world); endorsed the Rio Declaration on Environment and Development (27 principles guiding action on environment and development); and adopted Agenda 21 (a comprehensive action programme to help achieve a more sustainable pattern of development. The United Nations Commission on Sustainable Development (CSD) was created in December 1992 to ensure follow-up to and monitor report on implementation of the Earth Summit agreements at the local, national, regional and international level.

To mark the dawn of the new millennium, the United Nations adopted the Millennium Declaration in September 2000. The Declaration included resolutions on peace, security and disarmament; development and poverty eradication; protecting our common environment; human rights, democracy and good governance; protecting the vulnerable; meeting the special needs of Africa; and strengthening the United Nations.

The year 2002 marked the 10-year anniversary of the Earth Summit held in Rio de Janeiro, and to commemorate the milestone, a follow-up summit was held in Johannesburg, South Africa. This summit, known as “Earth Summit II” or the World Summit on Sustainable Development (WSSD), produced two key outputs: The Johannesburg Declaration on Sustainable Development (re-affirming the commitment of the world’s nations to sustainability); and A Plan of Implementation (building on the achievements made since Earth Summit I and expediting the realisation of the remaining goals). The summit adopted a number of commitments and targets in areas including poverty eradication, water and sanitation, sustainable production and consumption, energy, chemicals, management of the natural resource base, corporate responsibility, health, sustainable development of small-island states, sustainable development for Africa, and institutional framework for sustainable development; many topics relat-
Steel & sustainable development

Sustainable development and the construction industry

Construction forms a fundamental part of a society: its contribution reaches across a number of economic sectors and digs deeply into the very psyche of society. The nature of society in most civilisations is illustrated by the contributions made by their construction works. Construction surrounds us, determines the quality of our daily lives, and all the more so as the world transforms into a totally new society – the urbanised society.

Construction is a major contributor to economic growth and employment. Output worldwide in 1998 was estimated at just over US$ 3 trillion with in excess of 111 million employed in the industry [8]; by 2007 construction spending reached US$ 5.7 trillion. [9] However, as issues such as globalisation and environmental concerns are rapidly changing the operating environment, construction is expected to develop and implement the prerequisite adaptation and mitigation strategies.

Construction is a massive user of capital: Edwards [10] notes that global construction is responsible for:
- 50% of all resources used globally
- 45% of energy generated to heat, light and ventilate buildings and 5% to construct them
- 40% of water used globally for sanitation and other uses in buildings
- 60% of prime agricultural land lost to farming being used for construction purposes
- 70% of global timber products ending up in building construction.

Agenda 21 [7], adopted at Rio de Janeiro in 1992, establishes an agenda for sustainable development, and, as a consequence, a con-

Events related to construction

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<tr>
<td>1987</td>
<td>Our Common Future Bruntland Report</td>
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<td>1988</td>
<td>BREEM certification UK</td>
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<td>PassivHaus Germany</td>
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<td>Code for sustainable homes in UK</td>
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General events

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<td>Oil Schock</td>
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<td>1984</td>
<td>Bhopal gas leak in India</td>
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<td>1986</td>
<td>Chernobil nuclear accident</td>
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1 Data on the major global sources of carbon dioxide (CO2) emissions by country, from the beginning of the Industrial Revolution to the present. [2]
3 Phoenix (USA) at night - an area of high population density
4 Major events causing global awareness and their relation to the construction industry.
ceptual framework for sustainable construction that defines the links between the global concept of sustainable development and the construction sector and enables other agendas on a local level to be compared and coordinated.

The main challenges of sustainable construction which emerge are as follows:

- promoting energy efficiency
- reducing consumption of high-quality drinking water
- selecting materials based on environmental performance
- contributing to sustainable urban development
- contributing to poverty alleviation
- promoting healthy and safe working environments.

In 1996, the United Nations Conference on Human Settlements (Habitat II) in Istanbul defined goals in which the construction industry could play a direct and substantial role:

- changing unsustainable patterns of production and consumption
- avoiding environmental degradation
- promoting social and economic equality
- managing inadequate resources
- overcoming a lack of basic infrastructure and services
- overcoming inadequate planning
- mitigating against increased vulnerability to disasters.

More recently, and in response to the imperatives of climate change adaptation and mitigation, the United Nations Environment Programme (UNEP) published its report Buildings and Climate Change: Status, Challenges and Opportunities. [11] The report made a number of recommendations, including the need for:

- policies to encourage the wide support for more energy-efficient buildings
- benchmarking to quantify what may constitute an energy-efficient building under different conditions and for different typologies
- economic tools to impact on the economics of construction-related activities
- education and training to build knowledge and increase general awareness
- understanding human behaviour to influence how building occupants behave
- public sector to set an example for others to follow
- support technology transfer and improved access to technology.

In 2007, the World Business Council for Sustainable Development (WBCSD) released its report Energy Efficiency in Buildings: Business Realities and Opportunities [12], which collated the current state of energy demand in the building sector. Critically it concludes that it is possible to immediately drive down energy demand and reduce carbon emissions using technologies and knowledge already available today.

All these challenges require responses at different scales and by different players: of a component, by a producer; during the conception of a new product (based on the Life Cycle Assessment concept and on the ISO 14042:2000 standard); of a project, by a developer during the construction of a new building; of the construction industry or of part of it, by the agents involved; or by the government, as part of a public strategy, at local, regional, national or even transnational level; etc. With each scale comes a particular agenda, which must respect global issues and consider local particularities.

In response to these challenges, green building councils have been established in many developed and developing countries and have devised a set of practical and realistic requirements, indicators and criteria for evaluating the level of sustainability of a project. Most of them are related to an assessment method, and many to a certification process. Among these are BREEAM – Building Research Establishment Environmental Assessment Method (UK), LEED™ – Leadership in Energy & Environmental Design (USA), NF Bâtiments Tertiaires – Démarche HQE® (France), DGNB – German Sustainable Building Council, Minergie® – Swiss sustainability label, CASBEE – Comprehensive Assessment System for Building Environmental Efficiency (Japan), Green StarTM – Green Building Council of Australia and Green Building Challenge Assessment Method (international network).

The International Standards Organisation (ISO) has also produced the Technical Specification ISO/TS 21931-1 (framework for methods of assessment for environmental performance of construction works) [13], which proposes a structured list of issues for environmental assessment methods, corresponding to a common basic agenda for the building sector. These issues deal with environmental impact categories such as climate change, destruction of the ozone layer, depletion of non-renewable resources, formation of pollutants, formation of photochemical oxidants, acidification of land and water sources, and eutrophication. It calls for the inclusion of:

**Issues related to energy and mass flow during the project’s life cycle:**

- Material use, differentiated into depletion of non-renewable material resources, use of renewable material resources, and use of substances classified as hazardous or toxic according to national or international regulations
- Primary energy use, differentiated into depletion of non-renewable primary energy and use of renewable primary energy
- Water use
- Land use
- Waste management, differentiated into reuse/recycling or energy recovery and waste disposal.
Issues related to local impacts:
• on soil
• on ground water
• of noise
• of odours

In addition, it notes that the following issues of concern related to building management should be taken into account, where relevant: limitation of waste production, recovery of waste, reduction of nuisances, reduction of pollution, pollution control, water savings, wastewater treatment, maintenance, rehabilitation of the environment to promote biodiversity, and environmental emergency management.

With regard to the assessment of the indoor environment, the following issues of concern are noted:
• indoor air quality
• quality of ventilation
• hygrothermal conditions (air temperature and humidity)
• noise and acoustics
• glare
• access to daylight and exterior views
• quality of light
• odour conditions
• quality of water
• intensity of electromagnetic fields
• radon concentration
• hazardous substances
• the existence of unwanted micro-organisms, e.g. black mould

High-performance green buildings: The 21st century paradigm

Buildings are often used for centuries, but the rapid pace of development increasingly means that it is impossible to imagine the demands that future uses will place on buildings. Consequently, the designer should select products and systems that make adaptation easier. While aesthetic appeal will always be a component of building design, the real challenge is to create built environments that are durable and flexible, appropriate in their surroundings and provide high performance with less detrimental impacts.

In response to this challenge, a global initiative launched by the World Business Council for Sustainable Development (WBCSD) and supported by over 40 global companies, with the participation of major players of world’s steel industry, aims to “transform the way buildings are conceived, constructed, operated and dismantled” to achieve zero energy consumption from external sources and zero net carbon dioxide emissions, while being economically viable to construct and operate. Included in the initiative is the identification of the full range of present and future opportunities with regard to “ultra-efficient building materials and equipment”. Additionally, this aim is enhanced by using the “cradle to cradle” concept of producing, using and later reusing building materials, a design evolution needed to achieve sustainability for buildings.

The current generation of “green” buildings already offers significant improvements over conventional buildings, in as much as they consume less energy, materials and water; provide demonstrably healthier living and...
working environments; and greatly enhance the quality of the built environment, including the neighbourhood. However, these improvements are offered through the use of existing materials and products, design approaches, and construction methods. Because of this conventional approach to design and construction, it remains difficult to incorporate truly innovative technologies into current construction practice. Two schools of thought are emerging that address this challenge. The first relates to ‘high-performance green buildings’. The characteristics of high-performance green buildings, as suggested by Fujita Research [14] include:

- Optimal environmental and economic performance;
- Integrated processes, innovative design and increased efficiencies to save energy and resources;
- Satisfying, healthy, productive, quality indoor spaces;
- Employing lean construction methodologies and tools to improve waste management and reduce the environmental impact of construction waste;
- Increasing the emphasis, at R&D stage, of whole-building design, construction and operation over the entire life cycle
- Fully integrated approach, including teams, processes and systems
- Renewal engineering methods
- Management and business practices;
- New standards, open buildings, advance jointing and assembly techniques, process engineering
- Materials and systems: new function integrated building components, durability, ability to repair and retrofit components.

The second relates to ‘radical sustainable construction’. Radical sustainable construction has five major features:

- Integration with local eco-systems,
- Closed-loop material systems,
- Maximum use of passive design and renewable energy,
- Optimised building hydrologic cycles, and
- Full implementation of Indoor Environmental Quality measures. [15]

Steel solutions give answers to both schools of thought.

The role of steel in “radical high performance green buildings”

Good design is fundamental to sustainable construction. Decisions made at the initial design stage have the greatest effect on the overall sustainability of projects (see Chapter 3). The issues to be faced by radical high-performance green buildings favours construction products and methods that are flexible, light and durable. It is here that steel emerges as a material-driven construction system capable of achieving the prerequisite performance standards. The advantages encouraging the use of steel include its cost, non-combustibility, resistance to mould, gases, mildew and termites and its environmental friendliness. (Fig. 3)

Construction is a major consumer of materials and resources and thus it is imperative to reduce its resource consumption and to maximise material reuse. Prudent use of natural resources results in a more efficient industry and a restricted usage of natural materials. Practices such as materials recycling, waste minimisation, local product resourcing, land decontamination, and minimising construction- and demolition-waste disposal make sound business sense and encourage good construction housekeeping. Application of the principles of lean construction and life-cycle analysis, including life cycle costs (p. XX) are equally important. The steel industry itself is making huge strides in its efforts to achieve sustainable development imperatives. (Fig 9)

For example, the Canadian steel industry [16] has achieved:

- A reduction in carbon dioxide (CO₂) emissions of more than 20 % since 1990
- Emissions of sulphur dioxide (SO₂) reduced by 77 % since 1990
- Emissions of nitrogen oxides (NOX) reduced by 24 % since 1990
- Polycyclic aromatic hydrocarbons (PAH) emissions reduced by 74 % since 1993
- Energy efficiency improved by 25.4 % between 1990 and 2001, and
- Waste going to landfill reduced by 52 % between 1994 and 2002.

Under the drivers of mass production, quality control and cost reduction, technical progress has led to large energy savings and to the systematic use of lean and clean processes in steel plants. As a result, energy consumption and CO₂ generation in the steel industry have decreased. Western nations have reduced their relative CO₂ emissions by 50 % over the past 30 years, so that today, depending on the age of the plant and other factors, CO₂ emissions in Europe and the Americas average 1.5 to 2 t for each tonne of steel produced from iron ore. Furthermore, in respect of those figures, the effect of forty years of recycling has to be taken into consideration, when comparing with other materials. Water use in steel manufacture has been greatly reduced, and in most instances water is recycled and reused.

All steel production has a high recycled scrap steel content and all steel is recyclable. Steel is the most widely recycled material in the world: many steel components can be unbolted and even reused for future applications. The possibility of using building elements makes steel construction even more sustainable than the already significant contribution of today’s simple material recycling. Steel can be repeatedly recycled because it does not lose any of its inherent
The five major structural components of the project, namely, substructure, superstructure, elements and systems, enhance the sustainability of buildings in terms of these issues, and the economic and social performance of the project; in its phases – fabrication of products, design, erection, use and end of life. The following section is intended as a guide to assist designers who wish to adopt some of the above pro-recycling measures into their projects. It is structured around the five major structural components of building, namely, substructure, superstructure, roof assembly, services, and finishes.

Substructure
Construction challenges in substructures fall into both the environmental protection and economic growth sectors as the industry has significant impacts, both positive and negative, on the natural environment. Effective protection of the environment is possible through controlling and minimising the physical properties as a result of the recycling process. It also has vastly reduced energy and material requirements compared with steel made by refining iron ore: the energy saved through recycling reduces the annual energy consumption of the industry by about 75%, which is enough to power 18 million homes for one year. The steel industry has been actively recycling steel for more than 150 years: recycled steel provides 40% of the world’s steel industry ferrous resources. Steel recycling rates vary by product and geographical region: about 97.5% of structural steel beams and plates were recycled in 2004 and 2005, while the figure for reinforcement bars is about 65%. Structural steel sections generally contain about 95% recycled steel, whereas flat rolled steel contains about 30% reused material due to the different processes involved (see chapter 7). However, until now, global steel demand has always exceeded maximum recycling capacity, so that there is a still a need to produce new steel from iron ore.

The use of steel construction components, elements and systems enhances the sustainability of buildings in terms of these issues, and the economic and social performance of the project; in its phases – fabrication of products, design, erection, use and end of life. The following section is intended as a guide to assist designers who wish to adopt some of the above pro-recycling measures into their projects. It is structured around the five major structural components of building, namely, substructure, superstructure, roof assembly, services, and finishes.

Superstructure
The demands placed on buildings can change for a host of reasons, perhaps because of new technology or just a growing business needing more space. Whatever the reason, if a building cannot be easily adapted, then owners face the costs of demolition and redevelopment. Steel offers
Steel contributes to innovative solutions including demountable and reusable components, reduction of material volume by the use of composite members or innovative structural solutions, and the integration of structure and services. Furthermore, the rating tools award credits for a reduction in embodied energy and resource depletion associated with reduced use of virgin steel. Credits are typically awarded where a certain proportion of a building predominantly framed in structural steel has a post-consumer recycled content. Additional credits may be obtained if all the steel used in the building – structural, reinforcing/prestressing, and steel products – has a post-consumer content.

Because steel components are manufactured to standardised dimensions, there is often very little waste produced during construction, and that which is produced is in any event recycled, and does not present an environmental risk (contamination).

The application of steel technology in radical high-performance green buildings results in the use of industrialised components produced by modern manufacturing processes. These components are often highly prefabricated, which minimises the work on-site and reduces construction waste. Prefabrication takes place in a factory where safe, warm, and high-quality working environments can be provided (Figure 6). Components are delivered to the construction site on a just-in-time basis, where they are then assembled under much safer work conditions than would otherwise prevail. The benefits include lower site management costs and reduced storage and worker facilities, as well as less material damage and waste and a reduction of noise and particulate matter emissions into the atmosphere (mainly dust).

The cost of a construction project is the sum of materials, labour, specialist components, equipment, machinery and design costs. Steel construction achieves higher levels of productivity, thereby reducing labour costs both in the factory and on site when compared to conventional construction methods. The higher levels of prefabrication applied in steel-intensive construction systems also improves construction speed and safety.

Quality is a factor of ease of installation, good workmanship, material and component performance, reliability and design integrity – aspects which are far more difficult to quantify than cost. However, poor quality has a negative effect on construction costs and reputation. The elimination of wet trades, thanks to the use of steel components, reduces typical quality defects such as cracking, shrinkage, and poor finish, resulting in potential cost savings of 1 to 2 %.

The time taken to complete a project on site depends on the speed of construction. The quicker the construction process, the greater the potential cost savings due to lower on-site costs and interest payments, earlier income generation from sales or letting, and less disruption to users, especially in building alteration and extension contracts. Steel construction methods, because they rely on extensive prefabrication, are quicker to install on-site, thereby reducing on-site construction time (See chapter 3).

Comparative studies on the benefits of different forms of construction with various levels of prefabrication found that fully modular construction reduced the total construction period by 60 %; the time to achieve a weather-tight envelope by 80 %; and the proportion of total cost of on-site materials by 50 % compared to conventional construction. [17] In a separate study, lightweight steel frame buildings were found to be erected faster and more efficiently than buildings constructed with bricks or blocks, concrete formwork or pan- elised timber frame methods. [18]

Building reuse encourages and recognises developments that adapt existing buildings to minimise materials consumption. Steel-
frame buildings are generally the easiest to reuse due to their inherent flexibility and adaptability. Changes in the structural frame often require very little demolition work, and, with only a small amount of adjustment, a building can be put to a completely new use with basically the same structural system. Where the structural dimensions are not compatible with the proposed new use, steel frames can be disassembled and reassembled with very little loss of material content and value. Even in cases where the structural system is not suitable for reuse on a project, it can be sold or moved to another site and reused on a different project. Thus, high proportions of the existing steelwork or steel facades of a building can be reused. Material reuse encourages and recognises designs that prolong the useful life of existing products and materials. Because steel comes in standard sizes and sections, the designer can design a building in steel to reuse existing steel sections he knows are available. Thus, it is relatively easy to ensure that reused steel products and materials make up at least 1% of a project’s total contract value.

In spite of those favourable general characteristics of components and elements in steel, the option to use a certain product in a building should be taken into account tangible information on environmental performance. The correct method for manufacturers of building products to communicate the environmental characteristics of their products to developers, designers and specifiers is to use ISO 21930:2007. [19] This standard describes the principles and framework for environmental declarations of building products (EPD), taking into consideration the complete life cycle of a building. Nevertheless, as it is still a relatively new approach, the number of EPDs covering construction products made with steel or other materials is limited, but is going to be drastically increased by the global steel industry.

Green building rating tools generally encourage and recognise the environmental advantage gained, in the form of reduced transportation emissions, by using materials and products that are sourced within close proximity to the site. Transport of materials and personnel in construction is responsible for 10% of all vehicle movements across the EU, and 40% of the energy used during construction relates to the transport of materials and products. [20] Steel construction can reduce these impacts through:

- transporting prefabricated frames and modules;
- transporting more components per vehicle movement due to the lighter weight of the components; timing deliveries to suit traffic conditions; reducing the number of on-site workers and therefore worker flows to the site; and, as a consequence of less waste generation, reducing vehicle movements to landfill sites. Gervásio et al. [21] (2007) presented a comparative case study performed in order to evaluate two alternative structural systems of a dwelling from a...
sustainable point of view (environmental impacts and embodied energy):
• A light-weight steel frame
• A concrete frame.
Even though the authors state that their results are subject to a certain degree of variability, they concluded that “in both cases the structural system using the lightweight steel structure, irrespective of the end-of-life scenario, showed a better life-cycle performance compared to the concrete structure”. At all stages of the life cycle, the steel solution has a better performance with regard to embodied energy, which becomes higher due to the recycling and reuse of steel (allowing savings of approximately 50% of the embodied energy). Concerning environmental life-cycle analysis – human health, ecosystem quality and resources – the environmental impact of the lightweight steel house, irrespective of the end-of-life stage assumed for steel, is better than that of the concrete house, “although the difference depends on the scenario assumed”.
The adaptability of steel structures, cladding and partitioning can offer the designer the flexibility and scope to provide good daylighting, and to maintain unobstructed views.

Roof assembly
Technical progress is leading steel into a new era. Precision fabrication allows steel components to be made up in unprecedented ways using special steel sections, unusual angles and advanced CAD programmes. Structural steel will carry the required loads using a minimum amount of steel, while allowing the re-design of facades as the building’s need changes. Computer software helps determine how large openings can be, where they can be located and whether or not they require strengthening. Steel’s strength-to-weight ratio enables it to span large distances – more than any other building frame material. [22] The long-span capability of steel enables the creation of large areas of unobstructed space in multi-storey buildings. Steel is inherently ductile and flexible: It flexes naturally under extreme loads rather than crushing or crumbling. Steel structures also have reserves of strength. Steel is the only material that allows the strength of a structure to be increased economically after it has been built.

Steel’s high strength-to-weight ratio is exploited in lightweight structures that have low overall environmental impacts and often require fewer and lighter foundations than alternative methods of construction. Its long-span capabilities create flexible spaces that facilitate changes in use during the life of the building, maximising letting potential and reducing refit costs. Choosing the right material for roofing applications also contributes to limiting solar impact or to the exploitation of solar energy. A large range of colours and finishes of organic, metallic and even radiative coatings are available for steel solutions making them ideally suited to all kinds of climatic conditions.

In addition, a number of steel roofing systems exist which are compatible with renewable energy generation. These systems allow for the easy installation of photovoltaic panels, energy generation and solar absorbers for water heating. The structural properties of steel make it possible to install green roofs without adding undue structural loads. A green roof provides various benefits to a building, such as longer roof membrane life, acoustic insulation, and increased energy efficiency. In summer, a green roof shades the building from solar radiation and reduces heat gain. In winter, a green roof provides additional insulation, thus decreasing the amount of energy required to heat the building. On a larger scale, green roofs mitigate the heat island effect, thereby helping to bring down temperatures in the built environment.

Services
It must be noted that sustainability involves more than the choice of products and components, and that other sustainability benefits arise from improvements in the performance of buildings in service, including operations and maintenance, refurbishment, and demolition.

Life-cycle cost analyses also reveals that the operational costs of buildings are 100 times more than the construction costs over a 50 year period; therefore material choices and construction methods that reduce operational costs have a far greater influence on sustainability than first costs. The energy associated with the occupation of buildings (operational energy) exceeds that used in their manufacture and construction (embodied energy) typically by a factor of between four and ten over a 60-year design life. Reducing operational energy consumption reduces environmental impact as well as saving money. Due to internal heat loads from computers etc. and solar radiation in commercial office buildings, cooling is often the most significant energy use. Steel frames and associated composite members achieve high levels of fabric energy storage. Steel-based cladding systems for industrial buildings and light steel-framed residential construction provide well-insulated and airtight solutions. Designing buildings for long life and minimising operational burdens are key aspects of sustainable construction. Extending the life of buildings maximises value from the financial and material resource investment. These characteristics provide maximum flexibility in the subsequent modifying of an existing space. Steel framing and floor systems allow easy access to the fast-changing world of wiring, computer networking cables and communication systems without disrupting the operation of the facility or
people working in the area. All of the above increase flexibility of use in the medium and longer term, ease of extension and adaptation, recycling and reuse, and ultimately demolition and removal.

In a comparative study between the sustainability of a modular system of construction and an equivalent precast concrete structure, it was found that material use, waste and embodied energy were greatly reduced and the recycled content and recyclability were greatly increased by using a light steel modular form of construction. [23] The embodied energy in materials was reduced by 27%, equivalent to two years operational energy consumption. Operational energy was improved by 38% due to higher levels of insulation and airtightness in the manufactured units.

Designs that minimise greenhouse gas emissions generally consume less operational energy and maximise the potential operational energy efficiency of the base building.

Steel buildings can be easily designed to achieve and exceed the required base levels of energy efficiency, with the level of success depending on the detailed design of the building, its location and type of fuel used. Steel frame structures, facades and roofing systems readily accommodate high levels of insulation and flexible servicing strategies to maximise efficiency. Steel is dimensionally stable and can provide an exceptionally well-sealed building envelope for less air loss and better HVAC performance over time.

The efficient and effective use of steel sunscreens provides protection from the sun and helps to reduce solar heat entering the building. This is an effective strategy for reducing heat gain and lowering HVAC design loads and costs.

Historic buildings took advantage of fabric energy storage (FES) through the massive structures of walls and floors necessary in those days of low-strength materials. However, research undertaken by Oxford Brookes University and the European Union (EEBIS – Energy efficient buildings in steel) [xx] has proven that optimum levels of FES can be achieved in relatively light, structurally efficient buildings that are constructed from fewer resources. Using dynamic thermal modelling, the FES performance of common structural framing options were compared over a period of a year. The difference in the passive cooling provided by steel and by concrete-framed buildings was insignificant. In addition, a number of FES systems can be used in conjunction with steel-framed buildings, including passive systems in which the slab soffit is exposed or thermally permeable suspended ceilings are used, and active systems that include air core systems and water-cooled slabs. [xx]

In a similar research project, two experimental houses – one conventional and the other steel framed – were compared for energy efficiency. The results of the study showed that these means of energy savings are sufficient to reduce the heating energy demand by 50% compared to a typical Finnish row house. [24]

Green building rating tools generally encourage and recognise designs that reduce the consumption of potable water.

Steel construction is essentially a “dry” construction technology and therefore greatly reduces the amount of water used during construction. In addition, the prefabrication of steel components and modules takes place in a factory-controlled environment, where proper supervision and management of water use can be exercised.

Green building rating tools generally encourage and recognise designs that provide occupants with a visual connection to the external environment, achieve a high level of thermal comfort, maintain internal noise levels at an appropriate level, and use interior finishes that minimise the contribution and levels of volatile organic compounds (paints, adhesives and sealants).

Dry composite floors made with a steel deck achieve good airborne sound insulation levels with a comparatively simple structure. Experience with dry composite floors shows that, with adequate impact sound insulation, a sufficiently high airborne sound insulation level is reached automatically. Tests on real buildings demonstrated excellent acoustic performance.

The Stromberg Report [25] further examined vibration through the floors and found it to be satisfactory for single family houses. The report recommends certain interventions for multi-storey buildings where tenant expec-
Vibration tests carried out on the demonstration building where the design interventions had been applied yielded excellent vibration behaviour. The report noted the difficulties arising from thermal bridging and prepared design recommendations on thermal bridging, hygrothermal functionality and acoustic performance. The results from the experimental building showed that it is possible to achieve U-values as low as 0.1 W/m² °C. The report noted that air-change rates of less than two per hour at an over-pressure of 50 Pa could be achieved.

Finishes
Maintenance of buildings is vital to achieve longevity. Steel construction products require little maintenance, generally only where the steel is exposed to the elements or for aesthetic reasons. Steel components can often be used in their manufactured state, thus obviating the need for subsequent painting or polishing, and therefore also reducing the generation of indoor air contaminants. A wide range of advanced coatings is available for steel, and when used in accordance with the recommended maintenance programmes, these coatings offer excellent long-term protection with much reduced environmental impacts. Steel components that require painting are most often pre-painted in the factory under controlled conditions, with a consequent reduction of worker risk and off-gassing in the building. Low-emitting paints and coatings can also be used on steel to further this objective. In construction, durability and recyclability make stainless steel a clearly sustainable choice.

As a direct result of the material’s inherent properties, stainless steel does not require any coatings, while the upkeep and maintenance of a stainless steel product is simpler and its service life longer. Stainless steel is a durable material that does not age: Its improved corrosion resistance is due to the formation of a self-healing passive protective layer on the material’s surface. Subject to compliance with simple instructions that ensure the conservation of this protective layer, the material offers exceptional natural longevity (See Chapter 7). Stainless steel is also one of the most recycled construction materials. More than 90% of end of life stainless steel is collected and recycled into new stainless steel, without loss of quality. The high value of stainless steel scrap helps to ensure this recycling loop.

Steel – stepping into the 21st century

In high-performance construction, the key issue is how the choice of construction products and methods can create scope for reducing burdens. It is perhaps in this regard that the real role of steel in the 21st century construction will emerge, namely, an integrated and systemic approach to construction.

At a glance, the major environmental benefits of steel framing include:
• Recycled content and 100% recyclability;
• Minimum on-site waste due to high quality, shop prefabrication and standardised...
processes (two % for steel versus 20 % for wood);
• Life-cycle energy savings due to the insulation and air tightness of the envelope; and a long-lived structure that reduces the need for future building resources (zero depletion of iron resources).

A similar review of progress made in steel buildings demonstrated that:
• Steel construction is efficient, competitive and makes a significant contribution to society;
• Buildings can be rapidly constructed using high-quality, largely defect-free steel components that are efficiently manufactured off-site;
• Steel framing and envelope systems provide the scope, in association with other materials, to design buildings with low overall environmental impacts;
• Steel-based construction systems provide flexible spaces that have the potential to be easily modified and adapted so that the life of the building can be extended by accommodating changes in use, layout and size.
• At the end of the useful life of buildings, steel components can be dismantled easily; reclaimed steel products can be reused or recycled without degradation of properties.
• Off-site manufacturing facilities entail fewer itinerant workers, which, in addition to being safer, promotes stability in the workplace, encourages skills development and fosters good local community relations.

There is, however, an onus on manufacturers and suppliers to develop systems and methods for using their products that will facilitate designing for reduced impacts. There is, however, an onus on manufacturers and suppliers to develop systems and methods for using their products that can accommodate designing for reduced impacts. There is a further onus on developers, designers and specifiers to use these products properly. Key drivers of 21st century change that demand an appropriate construction sector response include the infrastructure needs of the growing global population, resource consumption, energy supply and global warming.

Steel's inherent qualities – including durability, non-combustibility, green attributes, safety social performance – coupled with a “pre-engineered” approach using design software designed for flexibility and emphasizing preparation and precision have all the attributes required by a 21st century construction sector.

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The benefits of steel construction when measured against the triple bottom line approach are the following:
• Economic – long lasting flexible buildings retain their economic value at the end of first use;
• Social – the demountable stadium was a key element of London’s successful bid to stage the most sustainable Olympics ever and generated a six-year feel-good factor for the country.
• Environmental – buildings that can easily be adapted and re-used avoid demolition and the associated disruption and waste.

The efficiency of steel construction can, therefore, encourage new building to achieve higher standards and improve the economic, social and environmental performance of the activities within them, while steel’s inherent adaptability provides flexibility for an unpredictable and rapidly changing future.

Thermal inertia is not related to the mass of a building. Phase change materials store thermal energy based on aggregation state changes from “solid” to “liquid”. They are micro or macro encapsulated and either based on salts or paraffins. The melting process at 24-28°C absorbs energy keeping temperature at a comfortable level. Solidification at lower temperature gives back this energy to the ambience, permitting a sustainable energy management of light steel buildings.