Sustainable Concrete Solutions

Costas Georgopoulos
and Andrew Minson

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Professor Costas Georgopoulos
Chair in Structural Engineering Practice
Kingston University London

Dr Andrew Minson
Executive Director
MPA - The Concrete Centre

WILEY Blackwell

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Sustainable Concrete Solutions

Foreword

Professor Jacqueline Glass
Chair in Architecture and Sustainable Construction
Loughborough University, UK

This book on sustainable concrete solutions sets out a practical and up to date manifesto for the design engineer to create low carbon, sustainable buildings and civil infrastructure using concrete. The materials that make concrete are global and plentiful, but we have a duty to deploy them in an environmentally sensitive and socially responsible manner. This publication by Georgopoulos and Minson brings together the current thinking on engineering design practices and materials science – an unusual and helpful combination for the engineer keen on delivering more sustainable buildings and civil engineering projects.

Beyond the introduction of sustainable development principles, there is a healthy balance of theory here, which is appropriately and neatly articulated with practical considerations. This is reflected in the logical structure which acknowledges implicitly the significance of the role of decision-making in the design process which is, ultimately, a key determinant of the success of sustainable buildings. Written through the eyes of a design engineer, the publication essentially shows how we can avoid the specification gap which often prevents projects achieving their full sustainability potential. Examples and case studies are featured extensively.

Indeed, the book is very much written with the designer in mind and while it covers the fundamentals, it also brings to light emergent challenges around life-cycle assessment and responsible sourcing of construction materials. What makes Georgopoulos and Minson particularly interesting therefore, is that it worthily and legitimately goes well beyond the more traditional interpretations of sustainability in the context of cement and concrete (i.e. replacing Portland cement).

This book is a valuable addition to the sustainable design and specification area and I would commend it to construction and engineering practitioners, academics and students alike.

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Preface

The challenges facing twenty-first-century humanity include climate change, natural disasters, population growth, overconsumption of resources, overproduction of waste and increasing energy demands. The sustainability opportunity for construction practitioners is to create a built environment that provides sustainable solutions with better whole-life performance by using less primary materials, less non-renewable energy, wasting less and causing fewer disturbances to the natural environment. Solutions are needed that will mitigate climate change, but also that help mankind address the consequences of climate change.

There is a growing pressure from governments and clients to create a built environment that meets the needs of today's communities without compromising the needs of future generations, in other words, a more sustainable form of development. Concrete is ubiquitous in the built environment being used in schools, hospitals, homes, offices, transport infrastructure, energy supply, water distribution and so on, for centuries and second only to water as the most consumed substance on earth. It is therefore essential that concrete is used in the most sustainable way and, this book contributes to constructing a sustainable built environment with concrete by offering a range of sustainable concrete solutions to practitioners.

Teaching and learning sustainability at universities is a challenge as it is a relatively new and fast evolving subject. In the UK it was initiated by the Royal Academy of Engineering in 1998 and incorporated into the competences of engineering graduates by the Engineering Council in 2004. Since then, sustainable development has been embedded into engineering curricula but very often, students and academics are not exposed to innovations in sustainable construction that are mainly developed by the industry. This book contributes to closing this gap of knowledge by offering a range of sustainable concrete solutions to students at all levels and academics of engineering and other construction related degree courses.

Specifying modern concrete mixes, designing to new state-of-the-art techniques and standards and, constructing using latest innovations are more challenging with demands to implement sustainability. The aim of the book is to serve as an introduction to and an overview of the latest developments in sustainable concrete construction. It provides useful guidance with further references to students, researchers, academics and practitioners of all construction disciplines who are faced with the challenge to design, specify and construct a more sustainable built environment.

Contents

1 Introduction

To set the scene, definitions of sustainability and sustainable development and the role of the design team in sustainable development are presented and followed by the sustainability credentials of concrete and, the book layout and context.

1.1 Sustainability and sustainable development

A distinction must be drawn first between sustainable development (the process, or journey) and sustainability (the aim, or destination). Sustainable development involves maintaining our current rate of development whilst leaving suitable resources behind for later generations to continue to develop. Therefore, environmental problems such as emissions must be tackled by considering their relationship with both the state of the economy and the well-being of society. We must take a holistic approach to each facet of sustainability: the environment, the economy and society. Taken together, this triple bottom line includes everything that we need to consider for a healthy, prosperous and stable life (Figure 1.1).

In the 1980s, increasing concern about the effects of economic development on health, natural resources and the environment led the United Nations to release the Bruntlandt Report 'Our Common Future', 1987. This report defines sustainable development as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs' (Bruntlandt, 1987).

The three strands of sustainability, that is, environmental, social and economic, being always diverse and sometimes conflicting can be used both as

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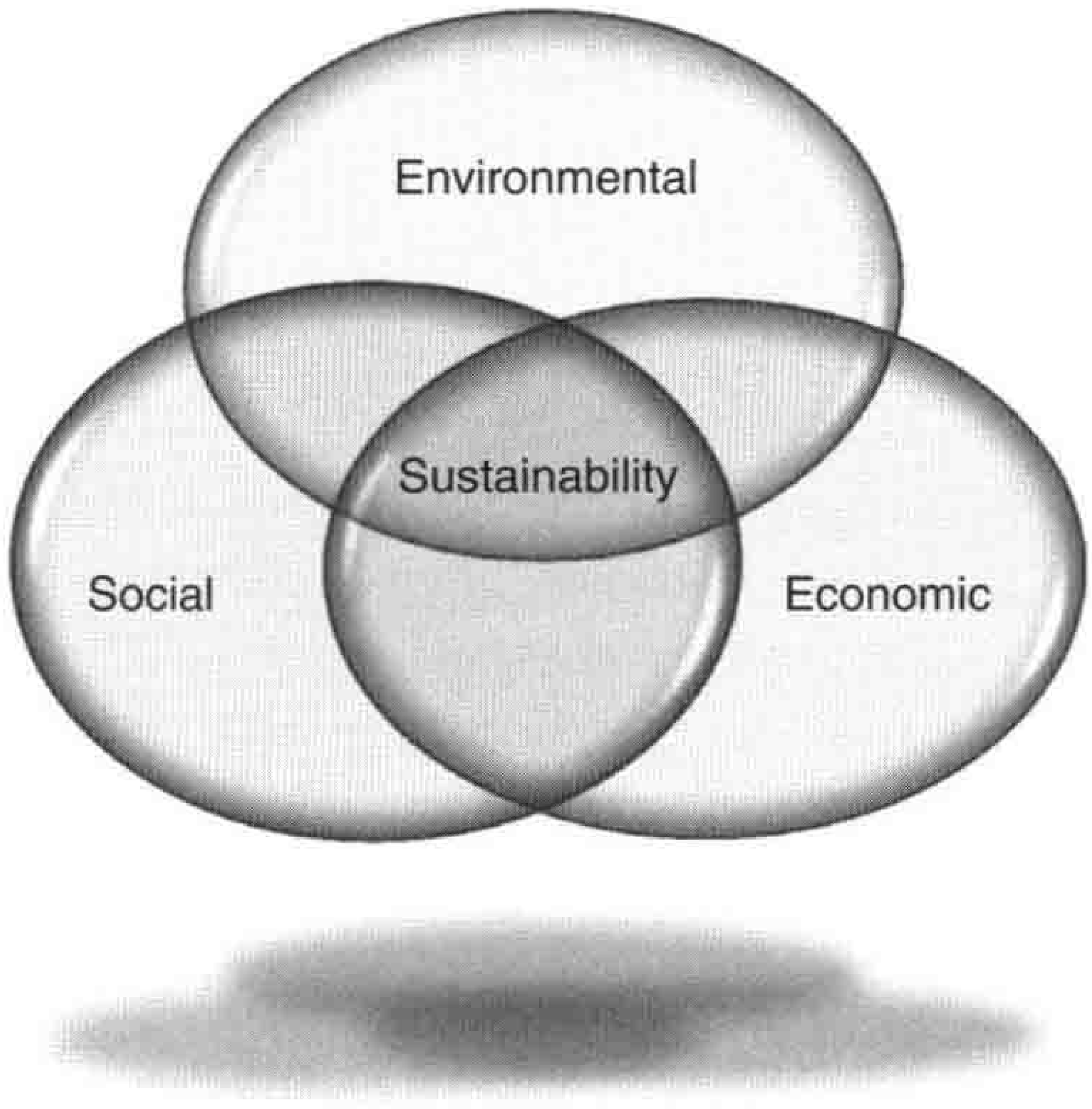

Figure 1.1 The triple bottom line of sustainability.

justification and as a barrier. For example, the London 2012 Olympic Park's environmental credentials - grey water recycling, combined heat and power plant, demountable structures, robust long lasting legacy structures - helped fulfil London 2012's pledge of hosting the most sustainable Olympic Games ever held and to establish sustainability benchmarks for the development of future Games facilities. Surely, one might argue, the most sustainable decision for London would have been to not hold the Games at all - not to use water and power, not to have hundreds of thousands of people flying to London, not to build structures for a few weeks. This would have been true if the emphasis had been placed on the environmental pillar of sustainability. Nevertheless priority was given to the economic and social pillars of sustainability as the Olympic Park helped regenerate the economy and society in a deprived area in London. Decisions are always based on one or more pillars on which emphasis is placed so projects always satisfy one or more pillars of sustainability. As a result, very few, if any, projects end up looking entirely unsustainable.

Although there are environmental impacts associated with cement and concrete production, we must not lose sight of the role that concrete and cementitious materials play in our built environment and the value of this built environment in our quality of life. The British Cement Association (BCA), in association with Forum for the Future, developed a business case for sustainable development with the purpose of assessing the costs and benefits of the UK cement industry in terms of its economic, environmental and social impacts (BCA and Forum for the Future, 2005). The overall findings of the business case are positive (Figure 1.2).

This work highlights the importance of approaching sustainability holistically; all facets, social, environmental and economic should be considered equally. To consider only one element skews the perception of the overall

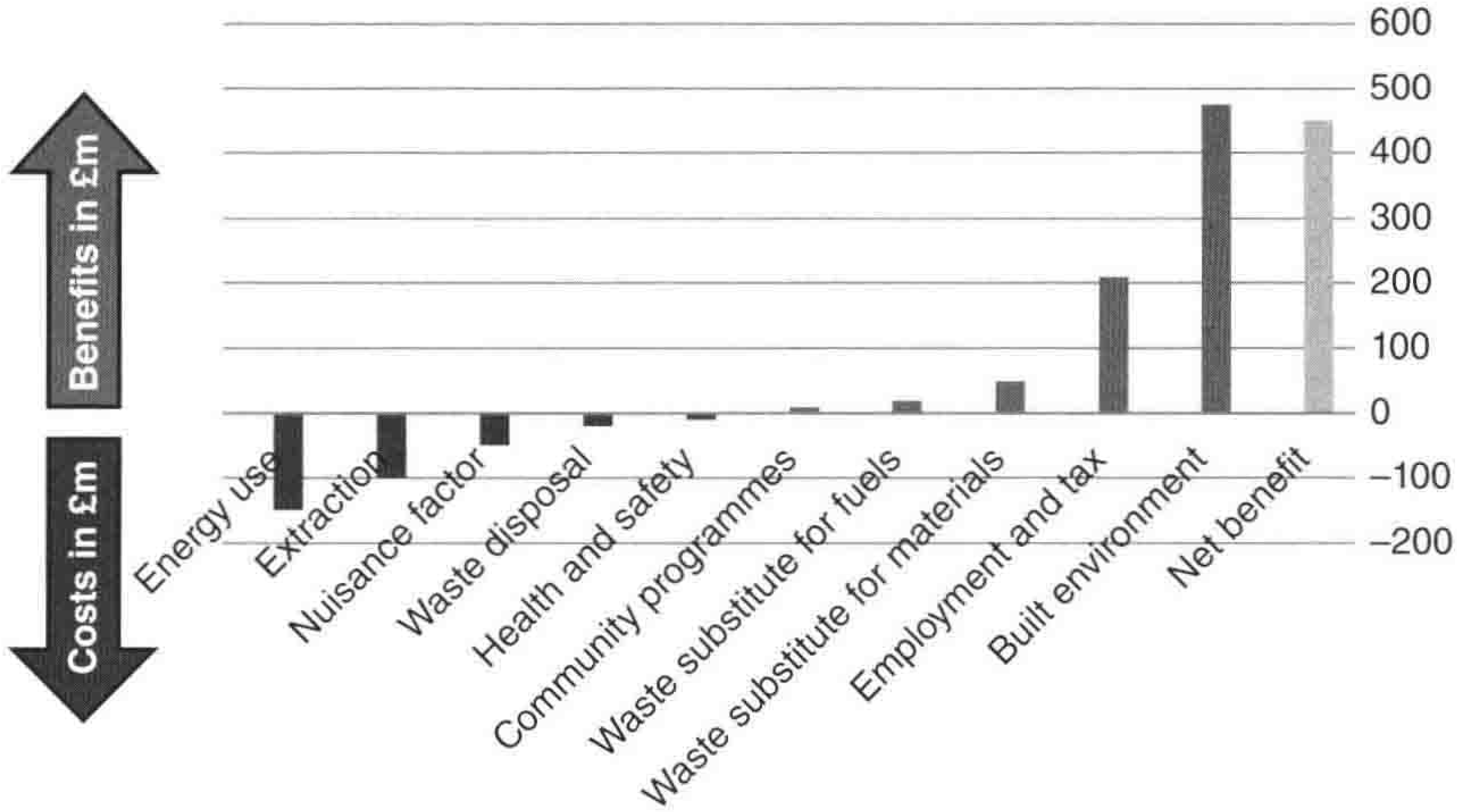

Figure 1.2 Cost-benefit analysis of cement production. Reproduced by permission of The Concrete Centre.

performance; embodied and in-use or upstream and downstream facets must be considered if we are to achieve real sustainability.

Detailed aspects of environmental, social and economic sustainability in construction are examined in Chapter 2.

1.2 The role of the design team in sustainable development

To enable the most sustainable construction and operation of a building the right decisions need to have been made at the design stage. A range of professionals have input into the design of a building and can contribute positively or negatively to sustainable development. A summary of the role of key contributors to the building design team is presented in Table 1.1. There is an overlap between roles, but for the purpose of considering sustainability, the different responsibilities have been allocated where possible. Some sustainability design decisions are truly integrated across several disciplines and this is indicated at the foot of the table.

1.3 Sustainability credentials of concrete

To demystify doubts about how sustainable concrete is, its sustainability credentials are presented in Table 1.2 and are further examined through the book. This draws on data obtained from the Sixth Concrete Industry Sustainability Performance Report (TCC, 2013) or is previously unpublished information from The Concrete Centre.

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Table 1.1 Opportunities to impact sustainable development (Minson, 2008).

Client	Architect	Structural Engineer	Services Engineer
To develop, reuse or maintain status quo Scale of development Functional requirements Location	Concept design Orientation Massing Cladding Internal finishes Fire* Acoustics* Lighting* Thermal comfort◊ Air quality◊ Minimum water use Landscaping Flooding New sustainable architecture	Structural materials specification Efficiency of design New structural concepts	Energy/CO_2 Thermal comfort Air quality Equipment specification Operation manual New servicing strategies
	← New integrated design solutions →		
← Long life/loose fit or Deconstruct/reconstruct →			

*Specialist consultancy (not tabled) may be used on larger/complex projects
◊Responsibility is another discipline listed in this table

Table 1.2 Summary of Sustainability Credentials of Concrete (drawing on data from published data (TCC, 2013) unless otherwise referenced).

The sustainability performance benefits of concrete

Fire

Environmental
Concrete does not burn and therefore it reduces noxious emissions from a fire, and wastage of materials.

Social
The resilience of concrete reduces damage and limits the potential loss of livelihood or homes through a fire. During construction there is no risk to neighbours of the concrete frame being a fire hazard.

Economic
Regulations require safe evacuation of occupants but not property safety. Concrete structures comply with life safety regulation but can also resist fire to enable cost-effective repair and re-use.

Thermal Mass

Environmental
Concrete's thermal mass allows it to be used to reduce heating and cooling energy of buildings.

Social
The thermal mass of concrete can be used to reduce overheating in a building. Occupants affected by public funding and CO_2 targets, in social housing and schools, are at risk of overheating if energy use cannot be reduced by no cost options.

Economic
Using the thermal mass of concrete will lower running costs of a building. It will also reduce the plant needed on site, leading to reduced maintenance costs.

Acoustic Performance

Environmental
Concrete has good acoustic performance and there is less reliance on finishes and materials which have a short lifespan. Hence less material is used and potential waste is avoided.

Social
Concrete's mass absorbs sound, ensuring quality of life, particularly in high density living, where dwellings are prone to acoustic break-in.

Economic
Concrete walls and floors provide required acoustic separation with minimum finishes, hence minimum cost and maintenance.

Durability

Environmental
Due to the long life of all concrete structures, material impacts on the environment are kept to an absolute minimum.

Social
The durability of concrete structures means that, once built, they are rarely out of use for maintenance and hence have minimum social disruption.

Economic
Concrete is a very stable and durable material with an extremely long life. As a result, maintenance costs are minimal for concrete structures.

Robustness/Security

Environmental
Concrete structures are robust, reducing risk of damage to finishes, hence less use of materials through the whole life cycle of structures.

Social
Solid concrete party walls provide safe, secure buildings. Prevention of intruders helps to build safer communities. Concrete infrastructure is robust against vandalism/terrorism minimising social disruption.

Economic
Concrete structures, particularly if finishes are minimised, will suffer less damage and cost less to repair and maintain.

Flood Resilience

Environmental
The flood resilience of concrete means it retains structural integrity, resulting in minimum wastage of materials following a flood event.

Social
A concrete structure will resist water penetration, keeping inconvenience and disruption to business, homeowners and the community to a minimum following a flood event.

Economic
Downtime of businesses, homes and essential community services, is minimised if flooded buildings are constructed in concrete.

The Sustainability Credentials of Specified Products: Precast, Ready-mixed and Reinforcement

Precast Concrete Products
CO_2: A commitment to use additional cementitious materials where performance requirements permit exists throughout the industry. Transport distance for the average delivery of precast concrete products is 106 kilometres.

(Continued)

Recycling: Recycling systems capture virtually all process water, slurry, aggregates or cement and these are re-used in the production process. Around 96% of the waste produced by the precast sector is recycled or re-used.

Resource depletion: Over 21% of aggregates used in the precast sector are recycled or from secondary sources. The sector has set a target to increase the use of additional cementitious materials to 25%. Precast products can often be re-used in their entirety.

Waste: The precast concrete sector uses more waste than it produces. A tonne of precast product uses 210kg of secondary materials and by-products and produces only 1.76kg of waste that goes to landfill. Concrete buildings can be designed with less finishes reducing the associated material waste.

Water: Dependency on mains water supplies is being drastically reduced across the industry as companies adopt recycling systems and alternative water sources such as rainwater harvesting. Approximately 132 litres of water are used per tonne of precast concrete product; 36% of which is from licensed non-mains sources. Water-reducing admixtures also minimise water use.

Emissions: The precast concrete sector is closely regulated by the Environment Agency. In 2012 the sector achieved an increase in the percentage of tonnage covered Environmental Management Schemes (EMS) to over 88%. A target has been set to increase this to 95% by 2020.

Biodiversity: Companies with factories in more rural areas are increasingly committed to protecting and enhancing the natural environment. A site in Yorkshire was the first manufacturing site to attain The Wildlife Trust's 'Biodiversity Benchmark'.

Health and Safety: The comprehensive British Precast health and safety scheme has helped members reduce their overall incidence rates by two thirds compared to 2000. Admixtures are used to produce self-compacting concrete which does not require vibration leading to quieter working environments.

Ready-mixed Concrete

CO_2: Additional cementitious materials and admixtures are used by most concrete manufacturers to optimise cement content and can reduce the embodied CO_2 of the concrete. Transportation CO_2 is minimal with the average delivery distance of ready-mixed concrete being 12 kilometres and 50% of ready-mixed plants are located at the aggregate extraction site.

Recycling: At the end of the life of a structure, all cured concrete waste can be recycled to create new construction materials.

Resource depletion: Every tonne of ground granulated blast-furnace slag (GGBS) or fly ash used in concrete mixes saves about 1.4 tonnes of raw materials and fossil fuels. Aggregates are abundant the world over and the UK has enough aggregate reserves to last for hundreds of thousands of years at current rates of usage (McLaren et al., 1999).

Waste: Modern formwork systems and efficient site management minimise ready-mixed wastage which is estimated at less than 2% of production output. Systems are available to re-use 'returned ready-mixed concrete' and this does not go to landfill. Concrete buildings can be designed with less finishes reducing the associated material waste.

Water: A cubic metre of fresh concrete contains 140 to 190 litres of water. The use of admixtures can reduce the water content by up to 30 litres per cubic metre. Ninety per cent of ready-mixed concrete already includes water reducing admixtures.

Emissions: All ready-mixed plants have dust suppression systems in place.

Health and safety: The ready-mixed sector is an increasingly safe place for people to work. Lost time injuries and reportable injuries to direct employees have been both reduced by a factor of 4 in the period 2009 to 2012 inclusive.

Sustainable formwork: Formwork suppliers and contractors have responded to the sustainability agenda by, for example, increasing the number of re-uses of formwork on site, refurbishing forms with surface treatment rather than replacing, and using vegetable-based release agents.

Reinforcement

CO_2: Manufacture of steel reinforcement bars for reinforced concrete could be a source of significant energy consumption and a large contributor to embodied CO_2. However, the UK industry uses the Electric Arc Furnace process, which generates up to six times less CO_2 than those emanating from the Basic Oxygen Steel making system that is used for making other UK steel.

Recycling: UK produced reinforcement for concrete is manufactured from around 94% recycled UK scrap steel. Scrap steel reinforcement from demolished buildings is recycled to manufacture new steel reinforcement. Two thirds of reinforcement used in the UK is produced in the UK. The majority of imported reinforcement is also produced from scrap steel by Electric Arc Furnace.

Resource depletion: The use of Electric Arc Furnaces allows reinforcement steel to be made from 100% scrap metal, reducing the specific energy (energy per unit weight) required to produce the steel, but also relieving pressure on the Earth's natural ore resources. The UK is a net exporter of scrap steel.

The Sustainability Credentials of Constituents: Cement, Cementitious Additions and Aggregates

Cement (MPA Cement, 2012)

CO_2: Direct annual CO_2 emissions were reduced by 44.8% since 1990 in absolute terms, thereby surpassing the UK's 2010 Cement Industry Climate Change Agreement target. The target was actually met four years in advance. This compares favourably with the UK construction industry, which overall recorded an increase in CO_2 of more than 30% over the same period (BCA, 2006).

Recycling: In 2011, the sector replaced 39.7% of its fuel from waste-derived material including scrap tyres, pelletised sewage sludge and meat and bone meal.

Biodiversity: All cement plants and quarries have, or are linked to, biodiversity action plans.

Resource depletion: The consumption of natural raw materials needed to make cement has reduced significantly over recent years. Between 1998 and 2011 the sector has increased the use of waste-derived raw materials by over 80%.

Waste: The cement sector is a net user of waste. Waste-derived materials are actively sought as replacements for natural raw materials and fossil fuels. In 2010 the sector used over 1.3 million tonnes of waste in this way and produced only 14,000 tonnes.

Emissions: The cement industry has worked hard to reduce its emissions to air by investing in new technologies. From 1998 to 2011 significant reductions have been achieved; SO_2 emissions have reduced by 84%, dust emissions by 82% and NO_x by 60%.

Health and Safety: Zero Harm is the overriding health and safety priority. Lost Time Injuries were reduced by 85% in the 8 years to 2011, and a target of 50% reduction has been set for the 5 year period to 2014.

Cementitious Additions

CO_2: The use of 50% GGBS can reduce embodied CO_2 by over 40% compared with a traditional 100% Portland cement concrete mix. Thirty per cent fly ash can reduce embodied CO_2 by over 20%. Limestone fines can reduce embodied CO_2 by 15%.

Recycling: The concrete industry recycles by-products from other industrial processes. GGBS, a by-product of iron production, and fly ash from electric generating plants can both be used as additional cementitious material in concrete mixes.

Resource depletion: Every tonne of Cementitious Additions used in concrete mixes saves about 1.4 tonnes of raw materials.

Waste: GGBS and fly ash are by-products of other industries. These products can be diverted from landfill by being used as Cementitious Additions in concrete mixes. As a proportion of total cementitious materials used in ready-mixed and precast concrete 30.2% is Cementitious Additions based on 2012 data.

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Aggregates
CO_2: On site CO_2 emissions from aggregates supply are 4–6kg per tonne. Fifteen per cent of UK aggregates are transported by rail and ship/barge. The average road delivery distance is 43 kilometres.

Recycling: With a growing commitment to recycling construction waste materials, there is now little evidence that any hard demolition and construction waste is sent to landfill (DCLG, 2007). Recycled and secondary aggregates account for 29 per cent of the total market: this is the highest for all countries in Europe.

Biodiversity: Over 700 Sites of Special Scientific Interest (SSSI) in the UK are current and previous sites of mineral extraction. The aggregates sector is actively involved in site stewardship and biodiversity initiatives, including encouraging exemplar restoration projects.

Resource depletion: Aggregates are abundant the world over. The UK has enough aggregate reserves to last for hundreds of thousands of years at current rates of usage (McLaren, 1999).

Health and safety: With improving working practices, year on year aggregate extraction is becoming an increasingly safe industry. The Mineral Products Association (MPA) achieved in 2012 their 2014 target of a 50% reduction in Lost Time Incidents (LTI) for direct employees and contractors, with an overarching aim of 'Zero Harm'.

Other Issues

Responsible Sourcing
The concrete industry is the first industry to link its sustainable construction strategy to the responsible sourcing standard developed by the Building Research Establishment (BRE), BES 6001 – 'Framework Standard for the Responsible Sourcing of Construction Products'. Ninety-two per cent of UK concrete is accredited as responsibly sourced. The reinforcement sector has both Eco-reinforcement which is accredited to BES 6001 and CARES Sustainable Reinforcing Steel Certification (Greenbooklive, 2012).

Local Sourcing and production
Local production using local materials is an important principle and covers social, environmental and economic aspects. For the UK, concrete and reinforcement are local products compared with alternatives that are imported, often from beyond Europe.

1.4 Book layout and context

After this introduction, Chapter 2 sets the scene by outlining the challenges of implementing sustainability in construction each followed by example responses drawn from the concrete industry. Chapters 3, 4 and 5 follow the logical sequence of a construction project, from inception to end of life, namely Chapter 3 on conceptual design, Chapter 4 on material specification and, Chapter 5 on construction, Operation and End of Life. Each chapter includes a summary and references at the end. The Appendix consists of specialised subjects and further information referenced in the main chapters. Appendices A, B, C and D cover thermal mass, biomass product substitution, options for concrete floors and worked example on embodied CO_2 for a building slab respectively. Concept definitions and where feasible case studies are included in the text.

In Chapter 2 the main challenges of implementing sustainability are presented, each followed by example responses drawn from the cement and concrete industries. The chapter starts with climate change, being sustainability's biggest challenge and causing temperature rise, flooding and wind damage. environmental protection is covered by looking at resource depletion, emissions reduction, transport of construction materials, preserving biodiversity and site restoration. Social progress follows under the headings of functionality, safety, durability, robustness and security, aesthetics, archaeology and community involvement. Economic growth is examined at national, local and household levels. Finally a section on regulatory responses outlines current global, European and UK regulations influencing progress in sustainability implementation.

Chapter 3 is the largest subject in the book covering the conceptual design of buildings and infrastructure. After a comprehensive introduction emphasising the importance of conceptual design, the buildings part starts with the client's brief followed by whole building design that includes design life and future flexibility, life time energy, design for deconstruction, orientation and integrated design. In keeping with the philosophy of moving from the whole to the parts, the following sections on buildings cover substructures, lateral stability, frames and flooring, cladding and roofs. Finally the buildings part is completed by looking at innovations, environmental assessment schemes and life cycle CO_2e studies. Conceptual design of infrastructure covers a selection of sustainable solutions using modern concretes or cements including ground remediation with stabilisation / solidification, hydraulically bound mixtures for pavements, road construction and pipes, new modular precast concrete bridges, sustainable urban drainage systems, wind towers and environmental assessment schemes.

Chapter 4 covers material specification being an integral part of the design process. The chapter starts with the introduction of new terms under the title Assessing Environmental Impacts of Materials that includes project context and functional equivalence, range of environmental impacts, life cycle of materials, life cycle impact assessment and, international standards and concrete product category rules. Responsible sourcing, being an increasingly important factor, is outlined next and is followed by the sustainability impacts and benefits of all constituents of concrete under the headings of cements and combinations, aggregates, water, admixtures, novel constituents and reinforcement. The chapter is completed with special concretes, specification examples and key guidance to specify sustainable concrete.

In conclusion Chapter 5 looks at construction, operation and end of life.

References

BCA and Forum for the Future (2005) *The UK Cement Industry: Benefit and cost analysis*, British Cement Association (BCA) and Forum for the Future, UK.

BCA (1999) *Concrete Through the Ages – from 7000 BC to AD 2000*, British Cement Association (BCA), UK.

BCA (2006) *Performance: a corporate responsibility report from the UK cement industry*, British Cement Association (BCA), UK.

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