SUSTAINABLE ASSESSMENT FOR GEOTECHNICAL PROJECTS

by

Daniella Godinho Abreu Holt

A thesis submitted in partial fulfilment for of the requirements for the degree of DOCTOR OF PHILOSOPHY at the University of Birmingham

Supervised by
Dr. Ian Jefferson
Dr. David D N Chapman
Honorary Professor Peter Braithwaite

School of Civil Engineering
University of Birmingham
July 2010

Abstract

Geotechnical engineering has a crucial role to play in enhancing sustainability due to its pivotal role in the construction process where potentially impacts are highest. Currently, there is a lack of methodologies for assessing geotechnical projects that truly encompass the three core pillars of sustainability. A robust system is required which offers an holistic approach that is both flexible and easily understood, whilst not being biased towards rewards or is prohibitively costly. In addition, 'tool fatigue', whereby a system is generated but never used, must be avoided. After a detailed evaluation of the systems available, the SPeAR® framework was selected. Following detailed discussion with a variety of practitioners, the methodology was significantly adapted to make it applicable to geotechnical problems and ensure that geotechnical engineers can understand and use it with relatively ease. The new version, called 'GeoSPeAR' in this thesis, allows for greater communication between masterplanning and geotechnical engineering via their common base, thus avoiding a potential barrier to greater adoption of more sustainable practices through the construction cycle. Three case studies demonstrated the assessment of the 'GeoSPeAR' methodology. These showed the practical application of the system and how this effectively supports geotechnical engineers in embedding sustainability into projects.

Acknowledgements

I am grateful to God for my life, for this opportunity and for all the wonderful people around me:

My mother Ruth, my everything.
My father Joao and sister Tatiana, far but not distant.
My husband Michael, my best friend.
My supervisor Ian, the lighthouse shining the way.
My supervisors Peter and David, always there for me.
Chris Rogers, who believed in me before I believe in myself.
Holt family, who loved me and supported me every step of this journey.
Mel and Mia, who let me be part of their family.
My friends, who pretended I was still there when I wasn't.
Helen and Sarah and the staff at the University, for every little help.

Without you, not one letter of this thesis could be written.

I also would like to thank the University of Birmingham, Arup and Skanska, companies that make a difference.

CHAPTER 1: Introduction

Sustainability has become a catchword of over the last decade or so and has been used and misused in many contexts (Dahl, 2008). The current view of the sustainability concept implicitly calls for a sense of responsibility and action sincerely aimed at improving or changing our current way of living, averting what many feel is an inevitable looming social, ecological, and economic crisis (Tibbs, 1999). More directly the concept of sustainable development (SD) demands nothing less than a substantial change in our modes of global consumption, production, technology, and decision-making in order to balance and achieve a socially sustainable way of living.

Over the last few decades governments across the world have gradually recognised the importance of SD values and the need to establish plans for action to implement the SD goals (Keijzers, 2004). In the UK this has resulted in pressure for the development of national and local governmental strategies (see Chapter 2). Moreover, the recent economic crisis and reports on climate change highlighted the unsustainable manner in which society exists and suggests that sustainability will be a very dominant theme in coming years if social, environmental and economic performance is to improve holistically.

Realising the significance and the impacts of the construction industry in the sustainability agenda in the UK, the UK Government published the first strategy for sustainable construction in 2000 (DETR, 2000). Since then this strategy has been frequently updated and the latest version was published in June 2008 (Strategic Forum for Construction, 2008).

Considering the motivation to embed sustainability into construction, research evolved to change methods and processes in order to include sustainable values into construction projects. Most of the research into the embedment of sustainability in the construction industry has been primarily focused at high level activities such as architecture and master planning. To date, however, there is still a lack of research and literature providing holistic guidance for geotechnical engineers on how to embed sustainability values into geotechnical projects (see Chapter 3).

Therefore, if sustainable outcomes are to be achieved in the near future and stakeholder's expectations about improving sustainability in the construction industry are to be matched, advances in sustainability need to be embedded throughout the construction chain including civil engineering and in turn geotechnical engineering. This is primarily because the construction industry (driven chiefly by governments) is developing and will continue to want to improve sustainability to higher standards, throughout all levels (DEFRA, 2009).

However, this requires further rapid development in guidance for geotechnical engineering to develop methodologies to communicate, assess and embed sustainability into current and future design practices (see Chapter 4).

There are several tools available to support sustainable assessment of master planning and civil engineering projects. However, the reality is that the geotechnical community does not make use of these high-level tools and is currently developing bespoke tools for specific areas of geotechnical engineering such as soil remediation (Hillier *et al.*, 2005; Jefferson *et al.*, 2007; Harbottle *et al.*, 2008). The development of partial systems for specific fields of geotechnical engineering does not address the whole geotechnical problem and has the added consequence of contributing to tool fatigue (Pediaditi *et al.*, 2006). In this manner, there is a gap in research regarding assessment systems for geotechnical projects as there is no sustainability assessment system yet established for used on geotechnical engineering projects (see Chapter 5).

To fill this gap, this research investigated how to support geotechnical engineers in embedding sustainability values into their projects. As a result an established assessment tool (SPeAR®) was adapted (see Chapter 6) and a seven step framework was developed to support the decision making process (see Chapter 7). This adapted system, called 'GeoSPeAR', aimed to aid the understanding of geotechnical engineers to the underlying issues of a project and the outcomes of each decision made through the geotechnical design process, thus allowing the improvement of sustainability to take place.

In Chapter 8, the 'GeoSPeAR' approach was used on three case studies, demonstrating how the assessment system works in terms of its practical application and how it can support designers in embedding sustainability into geotechnical projects. The results from the case studies are commented on and analysed in conclusions (see Chapter 9).

As a result of research work developed and presented in this thesis, a methodology was developed to support sustainability decision making in geotechnical engineering design. This thesis presents the development of a decision support framework, and its assessment through three case studies, in order to illustrate how this methodology can be used to engender greater sustainability within the geotechnical process.

1.1: Aim

The key aim of this research is thus to develop a framework to enable sustainability goals to be embedded into geotechnical projects through the development of a sustainability assessment system aimed specifically at geotechnical engineering.

1.2: Objectives

To achieve this aim, four objectives (intermediate targets) were fulfilled:

a) To discuss how sustainability in geotechnical engineering can be assessed

b) To develop a sustainability assessment system that is specific to the needs of geotechnical engineering

c) To develop a methodology/ process to guide geotechnical engineers through the assessment of sustainability

d) To show, via case studies, how the framework can guide geotechnical engineers in the embedment of sustainability into their design choices, in a consistent and objective way.

1.3: Contribution to knowledge

With this aim and objectives fulfilled this research has provided guidance for geotechnical engineers on how to improve geotechnical projects towards greater sustainability, which in turn supports sustainable construction and subsequently sustainable development goals. This has been achieved by having the development of a suitable framework and decision support tool by which sustainability and therefore sustainability benefits can be considered as part of the geotechnical engineering design process.

CHAPTER 2: Sustainable Development

2.1: History and context of the concept

The concerns of society about environment protection, conservation and social development are not new. Although this dialogue started with the gradual merging of the environmental movement and the post World War II international development community, many authors consider that the real motion of this process was started by the publication of “Silent Spring” by Rachel Carson in 1962.

From this, the concept of sustainable development was gradually developed over the following decades. Eventually, in 1987 in the report of the World Commission on Environment and Development entitled “Our Common Future” (Brundtland, 1987), provided the fist definition for the concept of SD, and was introduced in order to establish direct linkage between economic development and social and environmental problems (Shomberg, 2002).

This definition of SD was based not just on the assumption that there are shared linkages between social, environmental and economical development but, rather, that the issues themselves are inseparable in terms of their origins, their dynamism and their resolution. In other words, this definition of SD is founded on the argument that economic development and environmental protection are not mutually exclusive goals, but that both must be attained simultaneously if improvements are to be seen in global social human welfare (French and Geldermann, 2005).

Therefore to tackle economic development and environmental and social interdepencies, the Brundtland report called for political and economic change at the local and global level. The Brundtland report defines SD as a development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1997). In order to achieve this aspiration it contains two key concepts:

- The concept of need, in particular the essential needs of the world's poor, to which over-riding priority should be given
- The idea of limitations imposed by the state of technology and social organisations on the environment's ability to meet present and future needs (Shomberg, 2002)

In 1992, the concern about environmental, social and economic inequity and SD was echoed at the United Nations Conference on Environment and Development (UNCED) conference in Rio de Janeiro. The outcome of the conference, the Rio Declaration, consisted of 27 principles intended to guide SD around the world. With this document, informally known as the Earth Summit, the principles of SD were formally agreed and Agenda 21, a comprehensive plan of action for the 21st century was signed by well over 150 countries. At the same time the concept of SD was crystallised down to entail three pillars: economic development, social development and environmental protection (Shomberg, 2002).

The implicit generality of the Brundtland definition for sustainable development, together with the interest generated by the UNCED conference in Rio, has stimulated massive responses to the subject. Since then, much has been discussed internationally about what sustainability actually means in a practical way and how to move towards it. In the last few decades the concept of SD has been instituted as a guideline for humanity and established as a key subject for international agenda. The concept has been discussed in considerable detail and challenged, and many governments around the world have set up numerous organisations and strategies to deal with the subject (see timeline, Table 2.1; French and Geldermann, 2005).

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)	
Year	**Comments**
1962	• ***Silent Spring*** by Rachel Carson brought together research on toxicology, ecology and epidemiology to suggest that agricultural pesticides were building to catastrophic levels. This was linked to damage to animal species and human health.
1967	• **Environmental Defense Fund (EDF)** formed to pursue legal solutions to environmental damage. EDF goes to court to stop the Suffolk County Mosquito Control Commission from spraying DDT on the marshes of Long Island.
1968	• **Biosphere** Intergovernmental Conference for Rational Use and Conservation of the Biosphere (UNESCO) is held; early discussions of the concept of ecologically sustainable development.
1969	• **Friends of the Earth** formed as an advocacy organization dedicated to the prevention of environmental degradation, the preservation of diversity and the role of citizens in decision-making. • **National Environmental Policy Act** is passed in the U.S. to establish a national legislative framework to protect the environment. Sets the basis for environmental impact assessment in the world.
1970	• **First Earth Day** held as a national teach-in on the environment. An estimated 20 million people participated in peaceful demonstrations across the U.S.
1971	• **Greenpeace starts up in Canada** and launches an aggressive agenda to stop environmental damage through civil protests and non-violent interference. • **International Institute for Environment and Development (IIED)** established

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)

Year	Comments
	in the U.K. to seek ways for countries to make economic progress without destroying the environmental resource base.
1972	• **UN Conference on the Human Environment / UNEP** held in Stockholm. The conference is rooted in the regional pollution and acid rain problems of northern Europe. Leads to the establishment of many national environmental protection agencies and the United Nations Environment Programme. • **Environnement et Développement du Tiers-Monde (ENDA)** is established in Senegal, becoming in 1978 an international NGO concerned with empowering local peoples, eliminating poverty, and research for sustainable development.
1973	• **Chipko movement born in India** in response to deforestation and environmental degradation. The actions of the women of the community influenced both forestry and women's participation in environmental issues.
1974	• **Mario Molina and F. Sherwood Rowland release CFCs work** in the scientific journal, *Nature*, calculating that continued use of CFC gases at an unaltered rate would critically deplete the ozone layer. • **Latin American World Model developed** by the Fundación Bariloche. It is the South's response to Limits to Growth and calls for growth and equity for the Third World.
1975	• **Worldwatch Institute** established in the U.S. to raise public awareness of global environmental threats and catalyze effective policy responses; begins publishing annual *State of the World* in 1984.

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)	
Year	**Comments**
1976	• **UN Habitat.** First global meeting to link environment and human settlement.
1977	• **Greenbelt Movement** starts in Kenya. It is based on community tree-planting to prevent desertification. www.greenbeltmovement.org • **UN Conference on Desertification** is held.
1978	• **OECD Directorate of the Environment** relaunches research on environment and economic linkages.
1979	• **Convention on Long-Range Transboundary Air Pollution** is adopted. • **Banking on the Biosphere** IIED report on practices of nine multilateral development agencies, including the World Bank.
1980	• **World Conservation Strategy** released by IUCN. The section "Towards Sustainable Development" identifies the main agents of habitat destruction as poverty, population pressure, social inequity and trading regimes. It calls for a new international development strategy to redress inequities. • **Global 2000 Report released.** This report recognizes biodiversity for the first time as critical to the proper functioning of the planetary ecosystem. It asserts that the robust nature of ecosystems is weakened by species extinction.
1981	• **World Health Assembly** unanimously adopts a Global Strategy for Health for All by the year 2000.
1982	• **World Resources Institute** established in the U.S. Begins publishing biennial assessments of World Resources in 1986. • **UN Convention on the Law of the Sea** is adopted. It establishes material rules

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)	
Year	**Comments**
	concerning environmental standards as well as enforcement provisions dealing with pollution of the marine environment. • **The United Nations World Charter for Nature** adopts the principle that every form of life is unique and should be respected regardless of its value to humankind. It calls for an understanding of our dependence on natural resources and the need to control our exploitation of them.
1983	**Development Alternatives established in India**. It fosters a new relationship among people, technology and the environment in the South. • **Grameen Bank** established to provide credit to the poorest of the poor in Bangladesh, launching a new understanding of the role of microcredit in development.
1984	• **Third World Network** is founded as the activist voice of the South on issues of economics, development and environment. • **International Conference on Environment and Economics (OECD)** concludes that the environment and economics should be mutually reinforcing. Helps to shape the report, *Our Common Future*.
1985	• **Responsible Care,** an initiative of the Canadian Chemical Producers, provides a code of conduct for chemical producers that is now adopted in many countries. • **Climate change**, Austria meeting of World Meteorological Society, UNEP and the International Council of Scientific Unions reports on the build-up of CO2 and other "greenhouse gases" in the atmosphere. They predict global warming.

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)

Year	Comments
1987	• **Our Common Future** (Brundtland Report). Report of the World Commission on Environment and Development weaves together social, economic, cultural and environmental issues and global solutions. Popularizes term "sustainable development." • **Development Advisory Committee**. DAC members of OECD evolve guidelines for environment and development in bilateral aid policies. • Montreal Protocol on Substances that Deplete the Ozone Layer is adopted.
1988	• **Intergovernmental Panel on Climate Change** established to assess the most up-to-date scientific, technical and socioeconomic research in the field.
1990	• **International Institute for Sustainable Development (IISD)** established in Canada. Begins publishing the *Earth Negotiations Bulletin* as the authoritative record of international negotiations on environment and development. • **UN Summit for Children.** Important recognition of the impact of the environment on future generations. • **Regional Environmental Centre for Central and Eastern Europe** established to address environmental challenges across the region, with an emphasis on the engagement of business as well as governments and civil society.
1992	• **The Business Council for Sustainable Development** publishes *Changing Course*. Establishes business interests in promoting SD practices. • **Earth Summit.** UN Conference on Environment and Development (UNCED) held in Rio de Janeiro.

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)	
Year	**Comments**
	• Agreements reached on the action plan "Agenda 21" and on the Convention on Biological Diversity, the Framework Convention on Climate Change and non-binding Forest Principles. www.unep.org/unep/partners/un/unced/home.htm
1993	• **First meeting of the UN Commission on Sustainable Development** established to ensure follow-up to UNCED, enhance international cooperation and rationalize intergovernmental decision-making capacity. • **World Conference on Human Rights.** Governments re-affirm their international commitments to all human rights. Appointment of the first UN High Commissioner for Human Rights.
1994	• **Global Environment Facility.** Billions of aid dollars restructured to give more decision-making power to developing countries. • **China's Agenda 21.** White paper on PRC's population, environment and development is published. China sets an international example for country strategy for sustainable development.
1995	• **World Trade Organization (WTO)** established. Formal recognition of trade, environment and development linkages. • **World Summit for Social Development** held in Copenhagen. First time that the international community has expressed a clear commitment to eradicate absolute poverty. • **Fourth World Conference on Women** held in Beijing. Negotiations recognize that the status of women has advanced but obstacles still remain to the realization

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)

Year	Comments
	of women's rights as human rights.
1996	• **ISO 14001** formally adopted as a voluntary international standard for corporate environmental management systems.
1997	• **UN General Assembly review of the Earth Summit.** Special session acts as a sober reminder that little progress has been made in implementing Agenda 21 and ends without significant new commitments.
1998	• **Multilateral Agreement on Investment.** Environmental groups and social activists effectively lobby against the MAI. This, along with disagreement by governments over the scope of the exceptions being sought, leads to the demise of the negotiations.
1999	• **Launch of the first global sustainability index** tracking leading corporate sustainability practices worldwide. Called the Dow Jones Sustainability Group Indexes, the tool provides guidance to investors looking for profitable companies that follow sustainable development principles. • The UK Government publishes **"A better quality of life: A strategy for sustainable development for the United Kingdom".**
2000	• **UN Millennium Summit and the MDGs.** The largest-ever gathering of world leaders agrees to a set of timebound and measurable goals for combating poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women. Now known as the Millennium Development Goals, to be achieved by 2015.

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)	
Year	**Comments**
	• **The UK Government publishes a first strategy for sustainable construction "Building a better quality of life".**
2001	• **Fourth Ministerial Conference of the World Trade Organization held in Doha, Qatar,** recognizes environment and development concerns in the final Declaration. NGOs and the WTO agree to re-interpret the Agreement on Intellectual Property Rights regarding access to medicines and public health. • **China joins the World Trade Organization** accelerating national structural economic changes. The accession signals China's emergence, together with India and Brazil, as major new forces in the global economy.
2002	• **World Summit on Sustainable Development** held in Johannesburg marking 10 years since UNCED. In a climate of frustration at the lack of government progress, the Summit promotes "partnerships" as a non-negotiated approach to sustainability. • **Global Reporting Initiative (GRI).** After five years of a multistakeholder, consensusbuilding process, GRI releases its guidelines.
2004	• **Wangari Muta Maathai awarded Nobel Prize.** Founder of the Greenbelt Movement in Kenya, she is the first environmentalist to be awarded a Nobel Prize.
2005	• **Kyoto Protocol enters into force,** legally binding developed country Parties to goals for greenhouse gas emission reductions, and establishing the Clean Development Mechanism for developing countries.

Table 2.1: Important facts in the sustainable development timeline from 1962 to 2009 (IISD, 2009)	
Year	**Comments**
	• **Millennium Ecosystem Assessment released.** 1,300 experts from 95 countries provide scientific information concerning the consequences of ecosystem change for human well-being. • The UK Government supercede "**A better quality of life" for "Securing the Future - The UK Government Sustainable Development Strategy: Towards a global partnership for sustainable development".**
2006	• **Stern Report** makes the convincing economic case that the costs of inaction on climate change will be up to 20 times greater than measures required to address the issue today. • **NASA** reports recovery of the ozone layer greater due in part to reduced concentrations of CFCs, phased out under the Montreal Protocol.
2007	• **Public attention to climate change increases**. Former U.S. Vice- President Al Gore's documentary, *An Inconvenient Truth*, wins an Academy Award, and the Intergovernmental Panel on Climate Change's alarming forecasts about the planet's health make headlines.
2008	• The UK Government publishes a new strategy for sustainable construction: **"Strategy for sustainable construction.**
2009	• COP 15, the United Nations Climate Change Conference - Copenhagen, December 2009. (COP15, 20010)

Since being established as part of the international political debate in 1992, SD has been subject to subtle yet definite changes in its general meaning and context. While the text of the documents agreed at the Rio Conference in 1992 and the review summit in 1997 considered SD, the focus was more on environmental protection. More recently international documents have taken a broader perspective on the challenges presented by sustainable development by endorsing a wider concept including much more social development than had been previously (Kastenhofer and Rammel, 2005).

In particular, the present view of the sustainability concept implicitly calls for a sense of responsibility and action sincerely aimed at improving or changing our current way of living, averting what many feel is an inevitable looming social, ecological, and economic crisis (Tibbs, 1999). More directly the SD concept demands nothing less than a substantial change in modes of global consumption, production, technology, and decision-making in order to balance and achieve a socially sustainable way of living (Kastenhofer and Rammel, 2005).

2.2: Sustainable development timeline

The concept of SD has developed throughout the last few decades (see Table 2.1). Examining the main global related actions accompanying this trajectory it can be observed that the development of the SD concept comes from the acknowledgment and growing concerns about the accelerating deterioration on the natural environment, depletion of natural resources and the consequences of these for economic and social development.

As can be seen from the historical timeline (Table 2.1), much has happened concerning the development of the SD concept over the last few decades. Non-governmental organizations have taken the lead in discussing the concept of SD calling for action pushing the ideas at governmental levels. Governments around the world have been slowly developing strategies, documents and action plans for SD as a reaction to personal and organizational views on sustainability. Academics have been engaging in research to clarify the discussions and support reports and plans with scientific facts. Moreover, society has generally been more exposed to information about environmental, social and economic issues and the global perspective of implications associated with these for the future.

Recently, the ongoing fast globalization has resulted in increased dialogue about SD and has helped to improve debate. Moreover, the recent global economic downturn and the increased number of scientific and economic reports about the risks and impacts of climate change (Stern, 2006 and IPCC, 2007) increased discussions about the unsustainable manner in which we are living. In this way, to date there is a more general understanding that current global actions are failing to maintain environmental conditions for social and economic development, and also failing to direct society to sustainable economic growth.

In a practical way what it all means is that there is an urgent need to make a transition from an unsustainable to a more sustainable way of development. In order to do that there is a need to improve social and economic circumstances for all humans while maintaining the basic environmental conditions without which economic and social development cannot take place at all (see Figure 2).

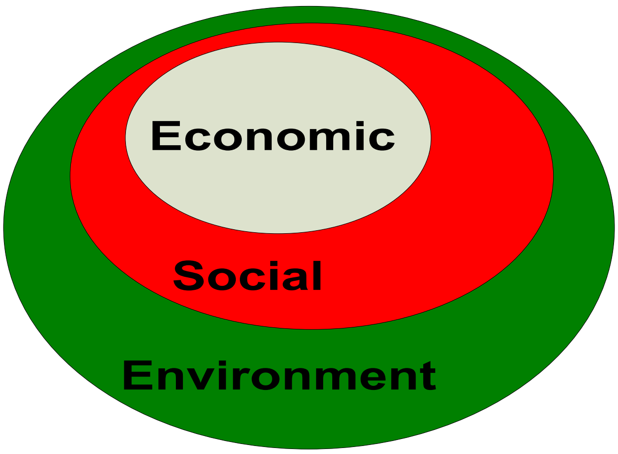


Figure 2.1: Graphical representation of environmental constraints on the economic and social development (Lozano, 2006).

2.3: Sustainable development values

In order to make a transition from unsustainable to sustainable it is necessary to understand what SD means in practical terms and how it can actually be achieved. Although it is widely accepted that there is no agreed definition for sustainable development the modern idea of SD is clearly founded on a core set of values described and established in September 2000 by the United Nations General Assembly in New York (see Table 2.2).

Table 2.2: Values underlying the Millennium Declarations (MD). (UNGA, 2000)
Freedom. Men and woman have the right to live their lives and raise their children in dignity, free from hunger and from fear of violence, oppression or injustice. Democracy and participatory governance based on the will of the people best assures these rights.
Equality. No individual and no nation must be denied the opportunity to benefit from development. The equal rights and opportunities of women and men must be assured.
Solidarity. Global challenges must be managed in a way that distributes the costs and burden of fairly in accordance with basic principles of equity and social justice. Those who suffer or who benefit least deserve help from those who benefit most.
Tolerance. Human beings must respect one other, in all their diversity of belief, culture and language.
Respect for nature. Prudence must be shown in the management of all living species and natural resources, in accordance with the precepts of sustainable development. The current unsustainable patterns of production and consumption must be changed in the interest of our future welfare and that of our descendants.
Shared responsibility. Responsibility for managing worldwide economic and social development, as well as threats to international peace and security, must be shared among the nations of the world and should be exercised multi-laterally.

The values shown in Table 2.2 represent the fundamental principles by which SD is currently based. They provide clear guidance about how international relations should be conducted if globalization is to become a positive force for all the world's people. Moreover, these values aim to express beliefs and define directions, frame attitudes, and provide standards against which the behaviour of individuals and societies can be judged (UNGA, 2000).

To translate these values into practical actions a chain of effort needs to be followed. To enable this translation to take place, there is need to identify and establish goals and key objectives to assure that SD values are connected to the activities associated with the process of implementing development into society at all levels.

Understanding the importance of setting clear key objectives, the UN together with 189 world leaders delivered in 2000 after the Millennium Summit, the Millennium Development Goals (MDGs). These set eight objectives to direct global activities. These goals were:

1. Eradicate extreme poverty
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improve maternal heath
6. Combat HIV/AIDS, malaria and other diseases
7. Ensure environmental sustainability
8. Develop a Global Partnership for Development

The MDGs aim to encapsulate SD aspirations for the world as a whole and the challenges that society face. Set for the year 2015, the MDGs are supposed to be achieved if all the governments who adopted the agreement work together in partnership supporting the necessary changes at regional, national and global level (UNGA, 2000).

However, given the lack of proper data from poor and developing countries, the measurement of the MDG's progress is controversial and therefore the MDGs are commonly criticized for being too broad and immeasurable. In spite of that, most governments engaged in this agreement still believe that the MDGs are valuable because they ignited global action and promoted a unique framework for raising the international cooperation needed to achieve SD (UN, 2010).

In response to criticism the UN set up a process to review the goals and the progress made towards achieving them. On 11 September 2008, the UN General Secretary launched "The Millennium Development Goals Report 2008" (UN, 2010), which included a review of the original MDGs and a global assessment of the progress. According to the UN this provided hard evidence for each of the eight MDGs, showing what has been accomplished so far in each of the world's major geographic regions. It also outlined what was needed in order to succeed in achieving these goals by 2015 (UN, 2010).

In this way the global SD agenda is currently set on the achievement of the MDGs goals and the success of this relies on each nation collaborating to improve its activities at international, national and local levels.

The MDGs goals provide a clear direction on where governments need to head towards and act upon to make a transition from unsustainable to sustainable development. Moreover these goals set the overall aims in which strategies and practical frameworks can be founded to practically develop a more sustainable society.

2.4: The UK agenda for sustainability

Over the last decades governments have gradually recognised the global importance of the SD values and the need to establish plans for action to implement the sustainable development goals (Keijzers, 2004). In the UK this resulted in pressure for the development of national and local governmental strategies.

Understanding the urgency for a national plan the UK Government published the first UK national strategy for sustainable development in 1999: "A Better Quality of Life" (DEFRA, 1999). Since then many other strategies and updated versions of this first plan have been published such as "Achieving a Better Quality of Life" (DEFRA, 2004) and "Sustainable Development Action Plan" (DEFRA, 2007) (see Table 2.3 for list of the UK Government national strategies). These documents aim to drive the sustainable development agenda in the UK and introduce national and local discussions on the way that business and other important areas of society are conduced (see Table 2.3).

Table 2.3: The UK national strategies from 1999 to 2009. (DEFRA, 2009)

2009	• **Sustainable Development Indicators in Your Pocket:** 2009
2008	• **Sustainable Development Indicators in Your Pocket:** 2008 • A**chieving Cultural Change:** a policy framework - This final discussion paper looks at how government policy can be used to encourage particular courses of action and behavior in cases where powerful cultural factors are at work.
2007	• **Sustainable Development Indicators in Your Pocket:** 2007 • **Achieving Cultural Change:** a policy framework - This draft discussion paper looks at how government policy can be used to encourage particular courses of action and behavior in cases where powerful cultural factors are at work.

Table 2.3: The UK national strategies from 1999 to 2009. (DEFRA, 2009)	
	• **Wellbeing and the Natural Environment: A brief overview of the evidence** • **UK Government Sustainable Procurement Action Plan (incorporating the Government Response to the Sustainable Procurement Task Force)**
2006	• **Sustainable development and wellbeing: relationships, challenges and policy implications:** a report by the New Economics Foundation. • **Review of Research on the Influence of Personal Well-being and Application to Policy Making:** Report by Professor Paul Dolan, Ms Tessa Peasgood and Dr Matthew White. • **Research on the Relationship between Well-being and Sustainable Development:** Report by Paul Dolan, Ms Tessa Peasgood, Andy Dixon, Melanie Knight, David Phillips, Aki Tsuchiya and Mat White. • **Procuring the Future** - Sustainable Procurement Task Force National Action Plan • **Review of Statutory Sustainable Development Duties:** Report by In House Policy Consultancy (IHPC) on behalf of DEFRA and the Sustainable Development Commission • **Securing the Regions Futures** - Strengthening delivery of sustainable development • **Smart Productivity** - Securing Sustainable Development in the English Regions. • **Sustainable Communities: A shared agenda, a share of the action.** • **Sustainable Development Indicators in Your Pocket: 2006**
2005	• **Government Response to the Committee's Thirteenth Report of Session 2003-04 The Sustainable Development Strategy: Illusion or Reality?**

Table 2.3: The UK national strategies from 1999 to 2009. (DEFRA, 2009)	
	• **One Future Different Paths - The UK's shared framework for sustainable development** • **Local Quality of Life Indicators - A guide to local monitoring to complement the indicators in the UK Government Strategy** • **Leading by example? Not exactly.... :** Sustainable Development Commission commentary on the Sustainable Development in Government Report 2005 • **Review of Funding for Education for Sustainable Development - Independent report** • **Securing the future - UK Government strategy for sustainable development:** Sustainable development Indicators in your pocket 2005 • **Sustainable development - Pilot study for public deliberative forum:** report of pilot study examining the potential to run a public deliberative forum on sustainable development.
2004	• **Achieving a Better quality of life:** review of progress towards sustainable development - Government annual report 2003. • **Driving public behaviours for sustainable lifestyles:** report 2 of desk research commissioned by The Central Office of Information (COI) on behalf of DEFRA. • **Government's Response to the Environmental Audit Committee's Eighth Report: Greening Government 2004 .** • **Quality of Life Counts: 2004 update**: Update on the UK Government's 1999 strategy core indicators of sustainable development. • **Regional Quality of Life Counts:** 2004 report giving regional information, where available, for the former 15 headline indicators (related to the 1999

Table 2.3: The UK national strategies from 1999 to 2009. (DEFRA, 2009)	
	Strategy) based on information up to 2003. • **Summaries of sources:** report 3 of desk research commissioned by The Central Office of Information (COI) on behalf of DEFRA. • **Sustainable Development Indicators in your pocket 2004.** • **Sustainable Development in Government:** Third Annual Report - Report on progress being made by Government Departments on integrating sustainable development into estate management and policy making. • **Taking it on - developing UK sustainable development strategy together:** consultation document to develop UK sustainable development strategy. • **The impact of sustainable development on public behavior:** report 1 of desk research commissioned by The Central Office of Information (COI) on behalf of DEFRA. • **World Summit on Sustainable Development:** two years on Government progress report 2004.
2003	• **Achieving a better quality of life:** Review of progress towards sustainable development Government Annual Report 2002. • **Government's Response to the Environmental Audit Committee Thirteenth Report (2002-03): Greening Government 2003** • **Regional Quality of Life Counts:** 2003 report giving regional information, where available, for the former 15 headline indicators (related to the 1999 Strategy) based on information up to 2002. • **Sustainable Development in Government:** 2nd Annual Report- Report on

Table 2.3: The UK national strategies from 1999 to 2009. (DEFRA, 2009)	
	progress being made by Government Departments on integrating sustainable development into estate management and policy making.
2002	• **Achieving a better quality of life review of progress towards sustainable development:** Government Annual Report 2001. • Government Response to the Environmental Audit Committee Fourth Report (2002) **Measuring the Quality of Life - The 2001 Sustainable Development Headline Indicators.** • **Regional Quality of Life Counts:** 2002 report giving regional information, where available, for the former 15 headline indicators (related to the 1999 Strategy) based on information up to 2001. • **Sustainable Development in Government:** 1st Annual Report - Report on progress being made by Government Departments on integrating sustainable development into estate management and policy making.
2001	• **Achieving a better quality of life:** Review of progress towards sustainable development Government Annual Report 2000.
2000	• **Greening Government Second Annual Report of the Green Ministers Committee Local quality of life counts: A handbook for a menu of local indicators of sustainable development**: Basic information about developing indicators of sustainable development for local areas. • **Regional Quality of Life Counts:** regional information, where available, for the 15 headline indicators.
1999	• **A better quality of life:** A strategy for sustainable development for the United Kingdom. (This document has now been superseded by the 2005 strategy).

Table 2.3: The UK national strategies from 1999 to 2009. (DEFRA, 2009)	
	• **Greening Government First Annual Report of the Green Ministers Committee Quality of Life Counts:** Report giving baseline data for sustainable development indicators supporting the 1999 strategy. (This document was updated in 2004 and has now been replaced by Sustainable development indicators in your pocket 2005).

Nevertheless the gap between publishing strategies and effectually changing the reality is still one of the main barriers towards achieving a more sustainable way of living. As the UK Government comments "to make sustainable development a reality the strategies need to influence, and to be built into, policies, decisions and actions at all levels" (DEFRA, 2007). In this way, to achieve this common objective different sectors of society and business need to understand the goals of SD, globally, nationally and locally and develop their own particular strategies and sets of indicators to be able to identify where there is real potential for improvement ultimately leading on to how best to embed the SD values on their activities.

2.5: Sustainability in construction

Realising the significance of the construction industry to the UK in terms of the social, economic and environmental aspects, the Government published its first strategy for sustainable construction in 2000 (DETR, 2000). Since then this strategy has been frequently updated and the latest version was published in June 2008 (Strategic Forum for Construction, 2008). More recently a progress report was published in September 2009 indicating progress made by both industry and Government in the various aspects embraced by the sustainability agenda (Strategic Forum for Construction, 2009).

According to the latest strategy the construction industry economic output is worth over

£1000 billion a year and it accounts for 8% of Gross Domestic Product (GPD), providing employment for around 3 million workers in the UK. Therefore, the activities of construction industry have huge impacts on the social and environmental aspects of life and in spite of the economic turmoil and the crises in the property market, construction is still one of the three biggest industries in the UK contributing to a large proportion of the economics of the country (Strategic Forum for Construction, 2008). Also according to the Government's strategy, the design, construction and operation of our built environment have other important economic and environmental effects, for example on the rate at which natural resources are used. Buildings are responsible for almost half of the country's carbon emissions, half of the water consumption, about one third of landfill waste and one quarter of all raw materials used in the economy (Strategic Forum for Construction, 2008). Construction also has a poor record in relation to people, especially for health and safety. Apart from the sufferings caused, this impacts the businesses not only in costly lost workdays, but sometimes leads to enforcement actions such as prosecution and site closure (DTI, 2006). Thus, the improvement of sustainability in construction activities can be directly linked to better economic, social and environmental activity in society and therefore is essential to moving towards SD. Overall, construction through its impact on the built environment and society plays a central role in promoting sustainable growth and development (see Figure 2.2).

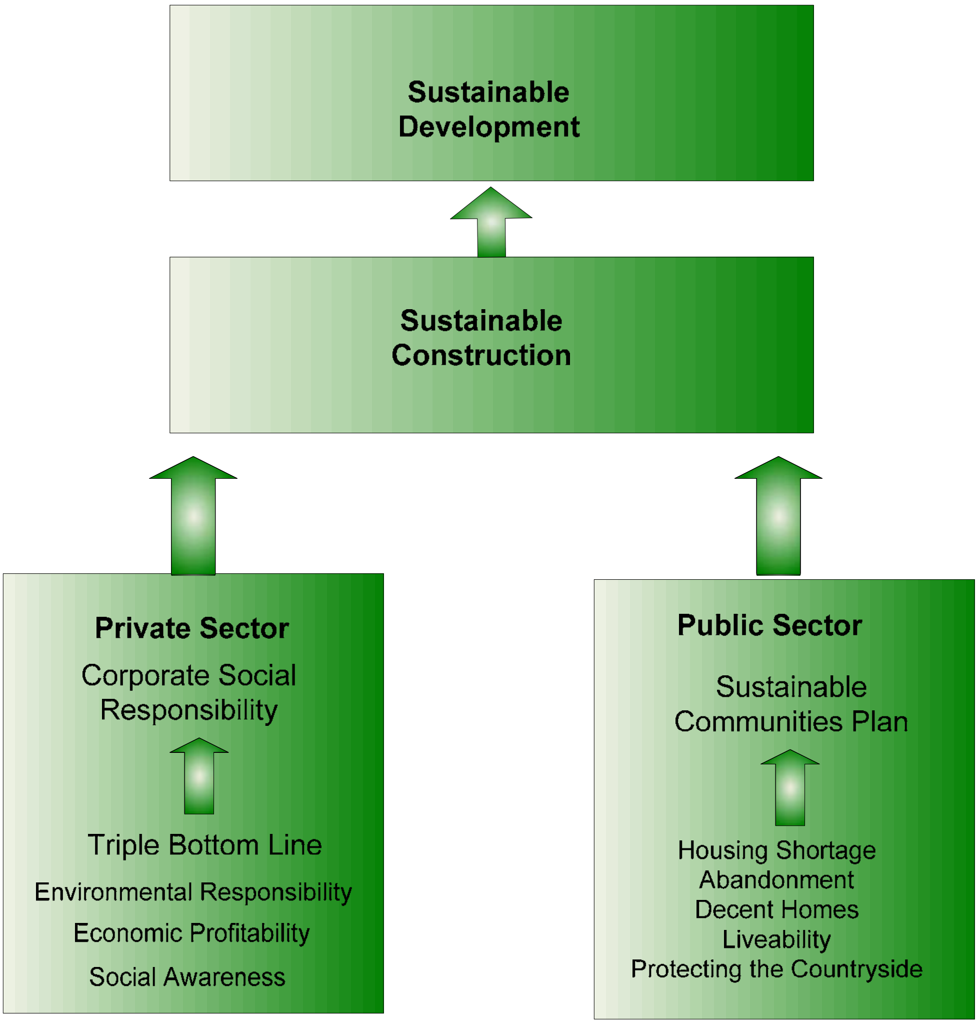


Figure 2.2: Sustainability in construction (WRAP, 2009)

Therefore, in the Strategy for Sustainable Construction the UK Government defined a set of overarching targets related to 'ends' and 'means' of sustainable construction. The 'ends' relate directly to sustainability issues such as climate change and biodiversity, and the 'means' describe process to help achieve the 'ends' (see Table 2.4 a) and b)).

Table 2.4: Set of overarching targets - UK strategy for sustainable construction (Strategic Forum for Construction, 2008)

a) The "Means"	
Chapter Heading	Overarching Targets
Procurement	To achieve improved whole life value through the promotion of best practice construction procurement and supply side integration, by encouraging the adoption of the Construction Commitments in both the public and private sectors and throughout the supply chain.
Design	The overall objective of good design is to ensure that buildings, infrastructure, public spaces and places are buildable, fit for purpose, resource efficient, sustainable resilient, adaptable and attractive. Good design is synonymous with sustainable construction. The aim is to achieve greater use of design quality assessment tools relevant to buildings, infrastructures, public spaces and places.
Innovation	To enhance the industry's capacity to innovate and increase the sustainability of both the construction process and its resultant assets.
People	An increase on organisations committing to a planned approach to training (e.g. Skills Pledges; training plans; Investors in People or other business support tools; Continuous Professional Development (CPD); life long learning). Reduce the incident rate of fatal and major injury accidents by 10% a year from 2000 levels
Better Regulation	A 25% reduction in the administrative burdens affecting the private and third sectors, a 30% reduction in those affecting the public sector by 2010.

b) The "Ends"

b) The "Ends"	
Climate Change Mitigation	Reducing the total UK carbon dioxide (CO_2) emissions by at least 60% on 1990 levels by 2050 and by at least 26% by 2020. Within this, Government has already set out its policy tat new homes will be zero carbon from 2016, and an ambition that new schools, public sector non-domestic buildings and other non-domestic buildings will be zero carbon from 2016, 1028 and 2019 respectively.
Climate change adaptation	To develop a robust approach to adaptation to climate change, shared across Government.
Water	To assist with Future Water vision to reduce per capita consumption of water in the home through cost effective measures, to an average of 130 litres per person per day by 2030, or possibly even 120 litres per person per day depending on new technological development and innovation.
Biodiversity	That the conservation and enhancement of biodiversity within and around construction sites is considered throughout all stages of development.
Waste	By 2012, a 50% reduction of construction, demolition and excavation waste to landfill compared to 2008.
Materials	That the materials used in construction have the least environmental and social impact as is feasible both socially and economically.

According to the Government, these are the basic points that need to be observed and improved if construction and sub-sectors (such as geotechnical engineering) are to become more sustainable. Most of these points simply make good business sense to achieve better building efficiency through whole-life performance, e.g. minimising waste to increase efficiency and using fewer primary materials to produce less waste and, to cause less disturbance to the natural and social environment. However, it is also essential to understand the significance of the non-technical soft social issues involved in the process of construction such as improving the levels of education and training of the people involved in the industry (Dickson, 2002).

Thus, given the room for improvement and the significance of the possible benefits to be achieved in construction, it is crucial that professionals in this industry understand their responsibilities and acknowledge the importance of developing mechanisms to overcome the current barriers holding back sustainable construction. Therefore, it is crucial to revise the current practices in construction and to encourage the industry to develop better products and process, which will contribute to a more sustainable built environment.

2.6: Main challenges to sustainable construction

Although, the sustainability agenda is increasingly gaining importance in construction and associated activities, to date there are still barriers preventing this new style of construction practice becoming the norm (E-CORE, 2005).

The first and most often mentioned barrier is financial. Financial restrains are often referred to as the main challenge for sustainable construction due to the extra time, skills and technologies associated with design and construction of sustainable projects. Although through life cycle cost analysis (LCC) many of the indirect economic benefits can be seen as investments over the long term, some clients may still be unsure about investing in sustainability due to the split gains between building owners and users in the way that investments on efficiency do not always return to those making the investment (WBCSD, 2009).

However, behaviour change of consumers towards a more sustainable way of consuming, legislation, governmental incentives, climate change and raising energy prices are randomly motivating key clients and investors to pursue more sustainable practices. In this way the landscape for offer and demand for sustainable projects is changing and this combined with better public policies that encourage the most sustainable approaches and practices may change the financial outcomes for sustainable construction in a positive way (Worldwatch Institute, 2008).

Other important issues that hold back the wider acceptance of more sustainable design and practice in construction are the technical barriers that can be encountered when using new processes and products in a sector that is traditionally very conservative and resistant to change (Edil, 2009). Therefore it can be very challenging to move forwards in adopting new design methods and new materials specification because, understandably, the nature of the sector is to avoid technical risks as much as possible. However, this can be problematic in different ways, such as getting approval from planning authorities, insuring the structures and providing warranties. To overcome these problems more governmental incentives are needed to test new methods and materials, but also more research is necessary to back up designers with sufficient data to overcome criticism and doubts about quality of new technologies, methods and materials.

In the same way, lack of know-how and experience of professionals designing sustainable projects can also be an extra technical barrier (Jarnehammar *et al.*, 2007). Without substantial knowledge about new technologies, processes and materials, designers often cannot satisfactorily inform clients of more sustainable options available. To overcome this, more knowledge transfer and training is necessary to share current successful models and further building know-how of sustainability in construction.

These are the main challenges preventing a faster improvement in construction practices. However, there are still more specific issues under these basic points that need to be tackled in order to advance the embedment of sustainability into the more specifics areas of the construction industry, such as design, civil engineering and geotechnical engineering.

In addition, the complexity and fragmentation in the construction chain also restrain a holistic approach to construction and becomes another limitation to the embedment of the sustainability values into the industry (see Figure 2.3) (WBCSD, 2008).

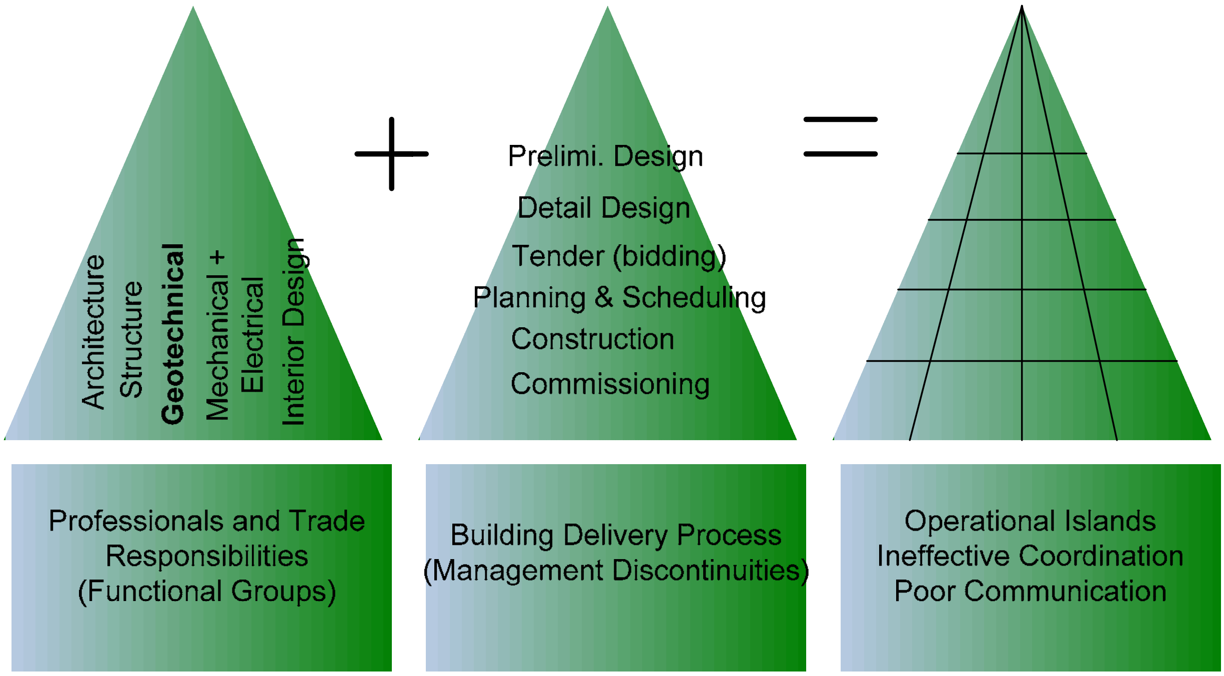


Figure 2.3: Complex value chain in the construction industry. (Modified from WBCSD, 2008)

As Figure 2.3 shows, the different links feeding the construction chain are many and intertwined, making it difficult to assess the effect of different choices and procedures. To overcome this barrier it is important to take a “bottom-up” approach to identify the barriers to sustainable construction and the means to overcome them, rather than proposing "top-down" prescriptions based on master planning or economy-wide data and analysis (WBCSD, 2008).

This bottom-up analysis must be applied to individual building subsectors, such as architecture, civil engineering and geotechnical engineering. In this way the prescriptions to overcome the barriers would be based on the specific characteristics and technical needs of each link of the construction chain, resulting in an overall improvement throughout the construction industry.

Therefore, if barriers are to be overcome at all levels of construction, there is an urgent a need to develop plans for each of the sub-sectors of the construction. Moreover, to implement the necessary changes needed to achieve more sustainable construction, all the sectors of the industry need to be equally engaged and committed in following strategies to mitigate the unwanted effects caused by construction and embrace the opportunities to improve the beneficial effects.

2.7: Sustainability for civil engineering

Collectively, civil engineering and its sub-sectors are responsible for delivering a great part of the infrastructure on which modern life depends such as clean water, wastewater treatment, transport systems. As such civil engineering is also responsible for a substantial type of input in delivering buildings, which directly affects economic and social development, such as houses, schools, hospitals. Thus, the civil engineering industry has huge potential to positively affect sustainable construction and subsequently sustainable development (Engel-Yan *et al.*, 2005).

However, the current approach adopted by most of the civil engineering industry remains essentially unsustainable. This chiefly results from the consumption of too much of the earth’s natural resources and the production of waste at a rate that cannot be sustained. Also, unsustainable civil engineering has other negative effects on society and the economy such as increase in heath problems developed by pollution and disruption of transport systems due to lack of appropriate logistics plans (Pepper *et al.,* 2007).

Despite improvements in processes and practices in construction and civil engineering in recent years (DEFRA, 2009) there is still a strong sense of imbalance between the positive and negative impacts in the delivery of civil engineering. Although methods have been partially adapted to become safer and more environmentally concerned, this has been driven largely by the development of legislation (such as the Environmental Protection Act 1990 (EA, 1990) and the Safety Representatives and Safety Committees Regulations (SRSCR, 1977). Thus the approach to improve procedures has been for the best part reactive to regulation and therefore limited and primarily focused in two basic areas: health and safety and environment protection.

In the 1970’s high rates of accidents and injuries in construction in the UK triggered detailed regulations such as Health and Safety at Work Act 1974 (HSE, 2009). As a result the construction industry recognised that the solution was to inculcate a good attitude towards health and safety risk management in civil engineering and construction professionals. Consequently methods were improved and, decades later, surveys demonstrate a high degree of improvement in the situation (particularly in the UK; Meldrum *et al*., 2009) Over time the knowledge in health and safety increased and much has been achieved in improving methods and practices at all levels of the civil engineering industry (Mihelcic *et al.,* 2003).

In a similar manner environmental issues concerning construction and civil engineering projects have been brought to the attention of the industry in the last two decades by

Government and dissatisfied stakeholders. Moreover sensitive subjects concerning the environment such as pollution have triggered a whole suite of environmental regulations, such as the Environmental Protection Act 1990. Very recently, climate change related issues and high carbon production by the industry have triggered legislation such as the Climate Change Act and the Carbon Reduction Commitment (DEFRA, 2010).

Thus, as the environmental impact of civil engineering encompasses a wide range of issues including mineral extraction, water usage and waste generation, several new pieces of legislation had come into place to regulate environmental impact of projects, for example via implementation of the Directive on the Landfill of Waste written in 1999. Following this, methodologies and processes have been developed to reduce environmental impacts of projects and also calculate environmental performance.

Searching for alternatives for reducing environment impacts, Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) have been introduced as a way of measuring the embedded life effects of product and projects. Over time ISO 14000 has become established in the industry and also assessment systems such as CEEQUAL have been developed to encourage the attainment of environmental excellence in civil engineering (more will be discussed about assessment systems on Chapter 4). Overall, in the same way in which the industry slowly absorbed health and safety legislation and new practices over the last three decades, environmental issues have been slowly absorbed by the construction and civil engineering industry in the last decade.

However, if sustainability is to be achieved in construction and civil engineering, a move away from a single concern from environmental issues to sustainability solutions is required.

In spite of all the recent improvement in processes and methods in health and safety and environmental protection development, there is still huge room for improvement in sustainability in civil engineering (Jeffereis, 2008). Thus, the challenge that needs to be tackled now is to embrace the full sustainability agenda considering the MDG's goals as priorities holistically. However to achieve this, the industry needs to develop methods to identify and eradicate hidden unsustainable patterns at all levels of the projects. The industry also needs to understand how to better engage professional civil engineers to commit to the sustainability agenda and more importantly to achieve a consistent approach throughout all fields of civil engineering.

2.8: Engaging engineers in sustainable activities

To encourage civil engineers to commit to the sustainability agenda it is crucial to first clarify objectives, the directions needed and understand where changes are necessary and are viable. With this in mind, the Institution of Civil Engineers (ICE), in the UK, delivered a Sustainable Development Strategy and Action Plan for Civil Engineering in 2007 (Pepper *et al.*, 2007). This strategy mainly explains the importance of embedding sustainability into civil engineering, but also incentive changes and directs these changes, by focusing on four main aims for action:

1. Promote strong leadership for sustainable development;
2. Embed the principles of sustainable development within civil engineering;
3. Build capacity for sustainable development in civil engineering;
4. Create and influence a policy framework that demands more socially and environmentally responsible behavior.

Moreover this strategy recognises the importance of working collaboratively with other disciplines across the construction sector so that issues surrounding the building of sustainable communities are considered holistically.

Thus, to improve the outcomes of projects, civil engineers have not only the duty of excelling in their own work, but also there is a need to interact with other professionals cooperatively to achieve better results. This requires sustainable thinking across all processes to create a balance between positive outcomes, avoiding adverse impacts of civil engineering and ensuring social benefits are accrue (The Royal Academy of Engineering, 2005).

Furthermore, the MDG's goals need to be built into everyday civil engineering decision-making process. Therefore, assessment systems need to be used as early as possible to support the decision-making process and maximise their efficiency informing decisions from early stages (Hunt *et al.*, 2008).

Additionally it is very important to build capacity for sustainable development equipping organisations and individuals with the understanding, skills and access to independent information, knowledge and training that enables engineers to perform effectively (Pepper *et al.*, 2007). Without properly trained and competent people contributing at every level, it is unlikely that the overarching aims of SD values and the MDG's goals will be achieved in civil engineering. Therefore it is crucial to incorporate the SD values into civil engineering education and training. In this way it is possible to develop an appropriated habit of mind and incentive attitudes that enable engineers of the future to better contribute to society (Jowitt, 2004).

Finally, the right policies and regulatory frameworks need to be in place to support more sustainable outcomes in civil engineering projects. To overcome economic challenges and help sustainable options to become established, policies are fundamental influencing costs of particular construction methods. Because of this, civil engineers and associated sub-discipline expertise engaged with sustainable development also need to be proactive in liaising with Government and clients to support legislation that promotes and incentive sustainable practices in construction.

Overall there is an urgent need for civil engineers, including geotechnical engineers, to realise their opportunities and responsibilities in improving sustainability in construction. Civil engineers at all levels, possessing the power over major decisions in construction projects are responsible for a broad range of inter-related social, economic and environmental issues and therefore need to act accordingly in a appropriate way to meet the needs and requirements of SD.

CHAPTER 3: Sustainability in Geotechnical Engineering

3.1: The role of sustainable geotechnics for sustainable construction

Geotechnical engineering, as an important field of civil engineering, has an important role in supporting sustainability in construction and thus sustainable development. This is because geotechnical projects have potential to interfere in many social, environmental and economic aspects of construction by the use of large amounts of natural resources, vast amounts of energy and fuel, and by the involvement in landform changes that potentially persist for centuries (Jefferis, 2008). Moreover, geotechnical engineering has huge potential to enhance the sustainability of projects due to its early position in the construction process, where impacts can be reduced and greatest gains can be made (see Figure 3.1).

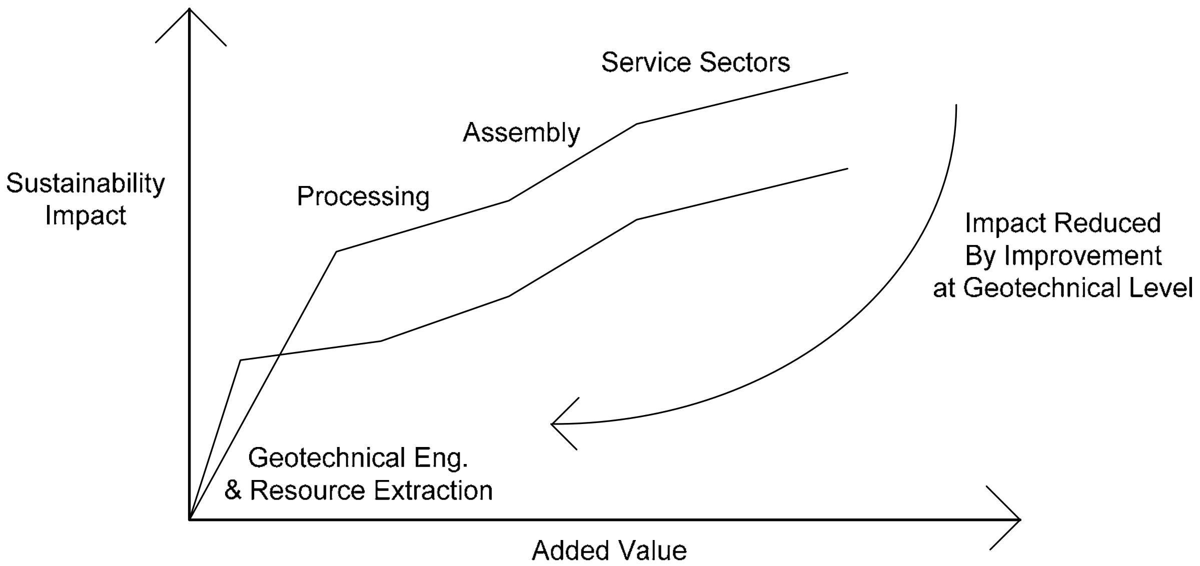


Figure 3.1: The sustainable impacts of geotechnical engineering

(modified from Jefferis, 2005)

Because geotechnical engineering works are at the start of the construction chain, geotechnical projects have the possibility to influence the decision-making process at early stages of design and construction, setting the sustainability values for the whole project, adding value and reducing adverse impacts.

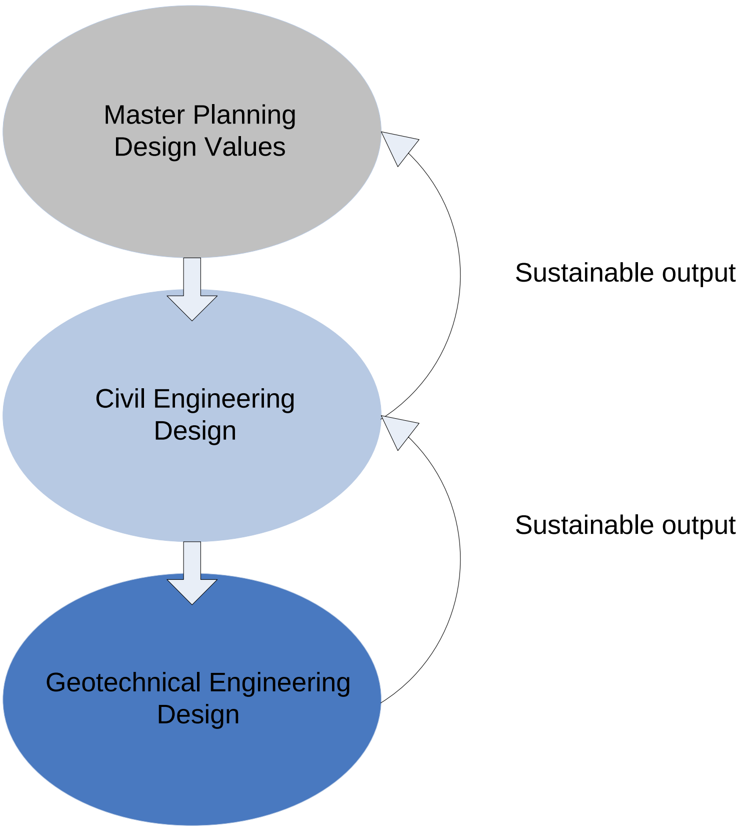


Figure 3.2: Geotechnical engineering in the construction chain

By embedding sustainability values throughout the construction chain (see Figure 3.2) it is possible to influence sustainable outputs at every stage of a project. In contrast without a sustainable output at different stages of a project, the aspiration for sustainability will be compromised.

As an example, in ground improvement and ground reinforcement projects, geotechnical engineers, by the development of more advanced techniques for utilisation of brownfield sites, can improve the sustainability and environmental credentials of projects from early stages (Simpson and Tatsuoka, 2008).

In a similar way the use of chalk fill as part of a motorway widening scheme in Kent, England (Phear *et al.*, 2003) illustrates the gains that can be made by geotechnical engineers at early stages. Here through effective communication with key stakeholders and careful process management, chalk spoil from the Channel Tunnel Rail Link construction was successfully used as a fill material, thereby making considerable cost and carbon savings while dramatically reducing the impact of a potential waste material. Other examples include the use of vegetation as a means of slope management, providing both biodiversity benefits and social enhancements through visual and acoustic screening along infrastructure corridors (Glendinning *et al.*, 2009). These examples highlight opportunities that geotechnical engineers have to reduce impacts and support sustainable development goals.

However, in order to fulfill the geotechnical potential in improving sustainable performance at the beginning of the construction chain, sustainable values need to be fully embedded into geotechnical design. This is because, without a sustainable outcome at the geotechnical level the full potential for sustainability of a construction project will not be realised (see Figure 3.3).

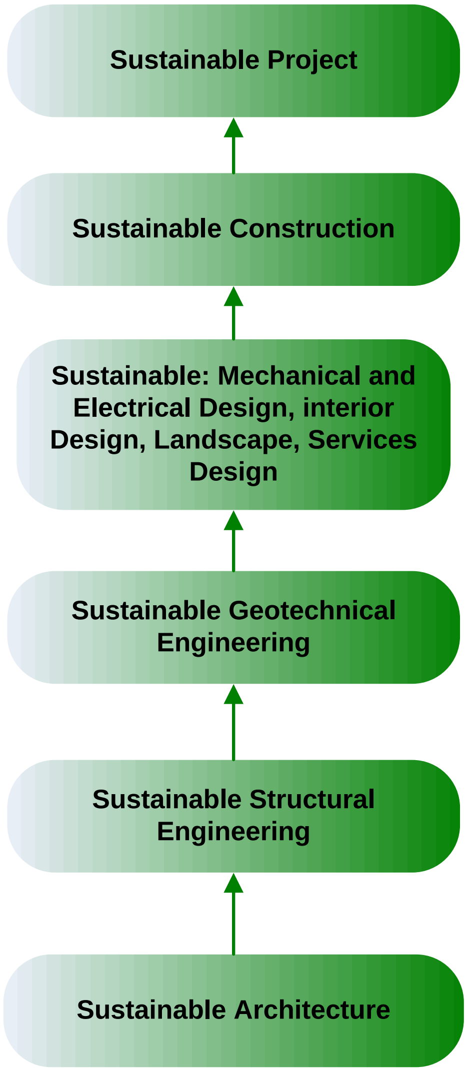


Figure 3.3: Necessary outputs to achieve a sustainable project

To fully embed sustainability into geotechnical projects, geotechnical engineers need to understand the impacts and effects of their projects, and address the complex issues of trade-offs in decision-making, whilst trying to embed sustainability values in every decision (Hunt *et al.*, 2008; Jefferis, 2008). However, to date, little formal help is available to guide designers in improving projects in a sustainable way. Also very little has been published providing more specific holistic guidance for sustainable geotechnical design.

Currently there is substantial literature on sustainability for high-level construction (Strategic Forum for Construction, 2008) but surprisingly not much is available regarding geotechnical projects. Few considerations of the whole sustainable value of a project have been made into geotechnical engineering literature (Hillier *et al.*, 2005; Jefferis, 2008; Panteliour, 2008). Some geotechnical researchers have considered the separated aspects of sustainability with reference to various projects that have proved more sustainable (this will be discussed in more detail in Chapter 4). However in general there is still complete lack of guidance about how to improve sustainable results in a holistic way in geotechnical engineering.

3.2: Sustainability and geotechnical engineering

In contrast to the immense amount of publications concerning sustainability to high-level construction and civil engineering, for geotechnical engineering very little has been made available concerning sustainable development and geotechnical projects (Jefferis, 2008; Holt *et al.*, 2010). In addition, little has been published about the consequences of maintaining the status quo in geotechnical design. In this way, without literature to give suitable feed back about the sustainability of geotechnical projects and current unsustainable practices, there is still a degree of contentment among the geotechnical community and this attitude does not help further research and improvements (Holt *et al.*, 2010).

So far, most of the research available has highlighted themes that can be considered as sustainability issues associated with the ground. This include: Response to climate change (e.g. Kilsby, 2009); management of environmental impact, e.g. reduction of carbon emissions (e.g. Chau *et al.*, 2008); developments of brownfield (previous developed) sites (e,g. CL:AIRE, 2010); greater use of the underground space (e.g. Hunt *et al.*, 2008); energy usage (e.g. Panteliour, 2008); geotechnical investigations and modeling to improve prediction and better understanding of geotechnical impact on the behavior of the ground (e.g. Kessler, 2008), all of which ultimately feeds through into design and construction activities associated with the ground (Simpson and Tatsuoka, 2008). All of these aspects impact directly on activity associated with the safe, effective and economic delivery of infrastructure and can be considered for convenience to encompass:

Ground as a resource – e.g. source of material, aggregate/fill or energy (geothermal)

Ground as a space for development – e.g. for utilities or transportation

Ground as a hazard – e.g. landslide, earthquakes or contaminated land

This highlights the key role, and therefore opportunities, for geotechnical engineering with reference to sustainability. While for construction and civil engineering many indicators systems had been developed, tested and established, for geotechnical projects few attempts had been made to address this subject (this will be discussed further in Chapter 5).

However, as noted by Jefferis, 2008; Jefferson *et al.,* 2007; Hunt *et al.,* 2008, there are many missing opportunities that are missed due to a lack of sustainable assessment methods aiming at improving sustainability in geotechnical projects in a holistic way. These authors are continuously highlighting the important connections between geotechnical projects and sustainable development and the relevance of providing real guidance for geotechnical engineers in order to embed sustainability values into geotechnical design and so improving industry performance across all three pillars of sustainability.

Some researchers have suggested the use of a single metric method as a proxy for sustainability assessment, drawing off the drive at national and international level to reduce carbon emissions or energy usage. These approaches have included life cycle analysis of differing geotechnical processes or systems to determine embodied energy (e.g. Chau *et al.*, 2008; Panteliour, 2008); carbon dioxide (e.g. Egan & Slocombe 2010) and even global warming potential (e.g. Storesund *et al.*, 2008). Although such approaches can be informative the use of a single metric fails to truly capture the complexities of sustainability, e.g. carbon dioxide emissions from the use of different aggregates fails to consider social impacts. As such there is a strong bias towards the environmental pillar of sustainability. Such approaches also suffer from potential limitation in data quality and can require assumptions that result in significant loss of transparency (Walton *et al.*, 2005).

An alternative approach uses multi-criteria analysis and is particularly useful when no quantitative data are available and allows stakeholder involvement. Such an approach allows social issues to be considered (Harbottle *et al.*, 2008). However, these approaches when used to assess sustainability can be time consuming through the need to engage with a number of stakeholders and the use of weighting limits the transparency of the results gain (see Chapter 5 for further discussion).

With other areas of construction and development the use of indicator based systems has proved useful allowing impact across all three pillars of sustainability (namely economic, social and environmental) to be addressed. However, if not considered carefully such systems can have an inbuilt bias towards rewards and can be costly to undertake (Jefferson *et al.*, 2007; Braithwaite, 2007).

Despite the lack of literature regarding sustainability as a whole and sustainable assessment for geotechnical engineering, there is growing literature concerning one aspect of sustainable development namely: environmental impacts of geotechnical projects. Given that there is general concern in the geotechnical community about the need to improve 'environmental sustainability' of geotechnical projects, the majority of the current geotechnical literature regarding any aspect of sustainability is focused on environmental aspects only.

Commonly, publications regarding this subject look at specific problems and isolated ways of improving environmental performance for geotechnical engineering such as reduction of embodied energy (e.g. Chau *et al.*, 2008), or recycling and re-using materials in geotechnical projects (e.g. Butcher *et al.*,2006). However, in most of this literature, no or minimal consideration is given to the importance of achieving a balance across the three pillars of sustainable development.

Strongly driven, primary focusing on the environment pillar are increasely occurring throughout UK Government focus on legislation as a response for climate change reports, population growth and resource consumption that is drawing down stocks of natural resources (Dahl, 2008). Thus, more attention is given to specific environmental aspects without holistic view of sustainability of a project

Moreover, as social impacts can be very complex and notoriously difficult to define and quantify there is a natural tendency of engineers to avoid dealing with social impacts of geotechnical projects. As engineers have general preference for dealing with subjects that are logic and numerical (Holvikivi, 2007), environmental aspects of geotechnical projects are more easily scaled and measured than social aspects. Through this general avoidance to deal with social aspects of geotechnical projects, little literature is available on this subject (Dahl, 2008).

However, sustainability can only be achieved in geotechnical projects if social aspects are balanced with environmental and economics aspects. Therefore, there is need to overcome the tendency to measure what is easily measurable (environmental and to a lesser extent economics) and avoid what is no so easily measurable (social). This is because to gain a full understanding of sustainability it is necessary to have some measurement of the social dimension of sustainability impacts (Henriques, 2010). In this way, for geotechnical research and literature to move forward overcoming the 'environmental only' focus, it is necessary to discuss sustainability in a holistic way, including any relevant social measures. Only then will proper guidance and support to geotechnical engineers in how to measure sustainability be provided.

3.3: Key research themes

The present research into sustainability aspects of geotechnical engineering lacks a complete sustainability focus and abounds in environmentally focused projects. In this manner the potential scope for discussion in each research topic is vast. However some key research subjects have been shaping the geotechnical way forward and have contributed to development of revised and more sustainable geotechnical methods.

To understand where we are, where we are going and how far we are in developing sustainability methods for geotechnical engineering and achieving the equivalent of the master planning benchmarks of sustainable construction, it is important to understand well the key research themes which have been setting new standards for geotechnical engineering lately.

3.3.1: Life cycle assessments

As research in geotechnical engineering has begun to broaden from its traditional emphasis, issues such as composition of materials, long-term environmental effects of design choices, energy and water usage, started to be assessed from cradle to grave revealing hidden impacts of projects and enlightening the decision-making process.

Life cycle assessment started to be introduced in geotechnical projects as a way of comparing design options. This implied that different options could be considered carefully against similar design criteria. In the same way different geotechnical construction and maintenance methods could be evaluated comparing similar indicators such as energy consumption. More importantly life cycle assessment systems bring to attention of geotechnical engineers their impacts both locally and regionally as well as at the global scales.

The inventory results of Life Cycle Analysis (LCA) can be translated into useful metrics such as CO_2 emissions and water consumption. These data can be further analysed using economic valuation by Life Cycle Cost Analysis (LCCA) or other evaluation techniques such as Multicriteria Analyses (MCA). Thus, based on the lifecycle assessment constructed with data from previous case of studies geotechnical engineers can learn how to reduce their impacts in specific matters by strategically assessing design options.

A simple and direct example of the use of LCA for research in geotechnical engineering can be seen in the study where the embodied energy of four different retaining walls systems was calculated and compared and the results helped an informed choice of material and design option to be made (Chau *et al.,* 2006). As for LCCA an example of this methodology applied to geotechnical benefit can be seen on the research where the Life Cycle Cost concept is introduced and a possible performance-based seismic design method for the future (Wang *et al.,* 2008).

However, LCA and LCCA methodologies still have several barriers that need to be overcome in order to become more practical for geotechnical design. Barriers such as time and cost, the need of human resources and knowledge, data availability and its quality, are still standing in the way of making life cycle assessments a more practical and established procedure (Azapagic *et al.*, 2008). Moreover, by using a single metric as a proxy for sustainability the subjective nature and complexity of the sustainability concept is completely ignored.

Research in this area is progressing and there are many expectations that the current barriers will be overcome or at least diminished, and the main benefits of LCA and LCCA will become more widely available for geotechnical designers. In the meantime, before data becomes more reliable and available driving costs and time down, LCA and LCCA can be used when there is time and economical resources available and specific details of a product or parts of a project throughout all life are needed.

3.3.2: Embodied Energy (EE) calculations

With the advantage of LCA in place, projects can also be analysed from cradle to grave revealing all sorts of hidden impacts. Thus, one main use for LCA in geotechnical engineering is to calculate the EE of structures in order to know the real energy consumption throughout the life of the project.

On this basis, knowing the total energy consumption of structures would help to inform the geotechnical designer when considering different design options and different materials (Chau *et al.*, 2008; Panteliour, 2008). Beyond this, knowledge of the embedded energy of projects can be used to identify inefficient methods and develop alternative procedures to save energy throughout the whole life of a project, from design to decommission.

Although calculating EE of a project is not a complete way to evaluate the sustainability of a project, it can be very useful as one indicator for sustainability. In this way in conjunction with other important indicators EE can become a very powerful part of a holistic process of evaluating the sustainability of a project (Panteliour, 2008).

3.3.3: Energy usage and carbon footprint

As the construction industry along with the UK Government is currently focused on reducing carbon emissions to comply with international climate change strategies (ICE, 2009) geotechnical engineers are also seeking ways of making geotechnical methods more carbon neutral.

Considering that buildings are responsible for considerable amounts of energy in most countries and the absolute figure is rising fast, as construction booms, especially in countries such as China and India, the need to reduce energy consumption and the carbon footprint of construction projects is essential (WBCSD, 2008). Thus, to develop technologies that can help to evolve efficiency of energy use in geotechnical engineering can make a major contribution to tackling carbon emissions and make projects more environmental responsible.

As its becomes possible to calculate the amount of EE and the energy usage throughout all life cycle analysis of projects, it is possible to calculate and understand the carbon footprint. Therefore geotechnical engineers, if data are available, can strategically use LCA and EE calculation methods to design and develop procedures which will considerably reduce the carbon footprint of geotechnical projects.

In this context several geotechnical research streams have developed ways of improving energy usage (or even developing alternative ways of using the ground as a source of energy) as a possibility of reducing the carbon footprint of projects. Examples of research topics which considerably reduce the carbon emissions of projects are: ReUse of foundations (Butcher *et al.*, 2006); Use of Recycled Aggregates in Vibro Stone Column Ground Improvement Techniques (Serridge, 2007); Ground Storage of Building Heat Energy (DTI, 2002).

These projects, in very different manners, reduced the usage of energy and the associated carbon footprint of geotechnical methods. This shows that in many ways, and in many areas of geotechnical engineering, there is room for carbon reduction and energy efficiency if engineers are required to assess their projects and revise their methods.

3.3.4: Land use and development

As land is a scare resource in a crowded country such as the UK, the pressures on land from competing uses such as development, recreation, nature conservation, water resources management, heritage and agriculture is high (CEEQUAL, 2008). Thus, development of existing brownfield sites, including contaminated sites, has huge implications in the UK for sustainable development.

In the past engineers have been enabling the development of brownfield sites unsustainably, by the simple processes of digging and dumping elsewhere or by breaking the pathway of pollution. Nowadays, legislation and stakeholders' expectations require more environmental and sustainable remediation solutions, possibly using transferable skills and techniques from other sciences, such as medicine, biochemistry, physics and biology (Simpson *et al.*, 2008).

Thus, a number of researchers have suggested that to continually improve brownfield remediation in a sustainable way, it is important to focus on new techniques, which can reduce environmental and social impacts at the same time that delivery economic value (e.g.

Simpson *et al.*, 2008; Bardos, 2009). Suggestions for further research in this field include:

(a) more sophisticated, possibly even ‘intelligent’, permeable reactive barriers

(b) heat treatments, perhaps harnessing solar power or geothermal power

(c) injected chemical treatments that would either ‘fix’ contaminants or create barriers

(d) the use of plants, possibly biomass fuel plants, to be grown on contaminated sites to ‘adsorb’ contaminants

(e) nanotechnology, such as the nano zero-valent iron technologies, in which highly reactive nano iron particles cause less reactive metals to precipitate onto them. It should be noted that present uncertainties about safety need to be tackled. Once achieved this technique may be suitable for the remediation of very deep plumes of contaminated groundwater, injecting nano-sized iron particles deep into the ground through wells.

(f) better risk assessment techniques, using a better understanding of the toxicology of isolated and interacting chemicals, possibly eliminating some current concerns (Simpson *et al.*, 2008).

Moreover, as the sustainability context of remediation has been discussed since the early 1990s, the approach to land use and remediation of contaminated land has been very much linked to sustainable development in the last decade and to sustainable assessment in the last few years. Therefore, as research in this field evolved, a paradigm shift also happened, from the assumption that all risk-based contaminated land management is intrinsically sustainable, to the recognition that remediation processes themselves have sustainability impacts that need to be managed (Bardos, 2009).

This understanding promoted a great stream of geotechnical research about sustainability for brownfield development. As result, networks, forums and research consortia (see SUBR:IM, RESCUE, NICOLE for examples) are starting to develop a wide range of tools and techniques to deal with this subjects and address the wider-ranging issues affecting brownfield development (Harbottle *et al.,* 2007; RESCUE, 2007).

Even more, as the land development field of geotechnical engineering advances towards embedding sustainability into its practices by the use of assessment systems, researchers and engineers start to talk about the possibilities of the establishment of a assessment systems (such as ISO 14000), which permit a common assessment framework to improve the sharing of information between practitioners (Bardos, 2009). This shows that as progress occurs in research and development of best practice, there is a need to understand better how to measure the sustainability of projects.

However, even though bespoke systems for individual fields provide some insight about how to approach sustainable assessment for specific projects, because they are bespoke and complex they are also unlikely to become established. Moreover, as bespoke systems do not provide general guidance for other geotechnical projects, many systems would need to be developed in order to assess geotechnical engineering as a whole (more will be discussed on the subject of indicators systems for geotechnical engineering on Chapter 5).

In this context we can clearly observe that research in sustainability is more advanced in the land development field of geotechnical engineering than in other fields. Also, engineers working in this field have a clearer understanding of the opportunities of adapting methods and changing procedures in order to become more sustainable.

3.3.5: Consumption – Intelligent use of resources

A ‘prudent use of natural resources’ is becoming one of the main themes for sustainable development, and thus for many of the UK strategies for sustainability and sustainable construction (Strategic Forum for Construction, 2008). Therefore, construction, civil engineering and geotechnical researchers have also increased attention to this theme in the last decade.

However, to improve efficiency it is necessary to improve design, construction and operation to conserve existing resources and generate less waste. Also it is important to re-evaluate specifications and remove barriers that prevent or inhibit the use of secondary or waste materials.

In geotechnical engineering, this subject had been explored by many different research projects and sub-divided in two key subjects:

(1) Efficient Design

Although improvement in design is a common theme in geotechnical research, conservative geotechnical design is still mainstream among geotechnical engineers because it is regarded as reliable and safe. However to ensure efficient and sustainable design methods there is a need for these methods to be constantly revised and sometimes substituted (Keeler and Burke., 2009).

Moreover, as geotechnical design techniques and technologies of instrumentation advance to help engineers to monitor the ground and understand better the behaviour of soils and structures, geotechnical design can also advance in efficiency. In this context there is research ongoing in improving geotechnical design for more efficient solutions. (Patel *et al.,* 2007; Millis *et al.,* 2008)

As a result more sustainable and lean structures are been designed and even alternative new structures are being proposed by the influence of research in efficiency. Successful examples of efficiency in geotechnical design can be seen when efficiency is the main agenda and engineers have the time, resources and proper investigation to work in improving design (see Yim, 2005 for example).

However it is important to understand that focus on efficiency only can also be unsustainable. To achieve sustainable efficient design it is important to evaluate the project holistically, considering social, economic and environmental issues. This is because every design decision will produce a cascade of multiple effects in each areas of sustainability (Keeler *et al.,* 2009; Fleming *et al.,* 2006). However, geotechnical research enclosing efficient design and social aspects of sustainability is still uncommon. Responsible sourcing and ethics of materials are other fundamental themes for sustainable efficient design uncommonly discussed.

Although the concept of 'whole design' and 'integrated design process' is becoming common language for buildings designers and architects (Keeler *et al.,* 2009), in geotechnical research very little has been discussed about this so far. This gap in research highlights the need to improve design methodologies in geotechnical engineering. If this is to be overcome, geotechnical engineers need to start to think holistically about projects rather than focusing solely on individual parts. Also, the design needs to be time proofed and to consider future implication by consideration of decommissioning, refurbishment or reuse, to be effective in whole life terms. This can include assessment of durability of selected materials and improved techniques to reduce the need for maintenance and repair (Martin, 2004).

(2) Resource Management

Another common theme across geotechnical research is resource management. As geotechnical engineers can be responsible for considerable amounts of earth and materials movements, it is crucial that geotechnical designers understand ‘material flow’, how to optimise it and how to identify opportunities to improve resource management (Raffield *et al.*, 2006). Although resource management is directly linked to design, some research projects focused more on resource management than others as aspects of sustainable design.

An example of this approach can be seen in the European project Re-Use of Foundations for Urban Sites project and its followers (Butcher *et al.*, 2006). This project focused on reusing existing foundations to reduce the requirement for new materials when redeveloping buildings. This has the added benefit of reducing the need for disposal of the old materials and the associated transport movements. To reuse foundations, structures and materials it is essential to think earlier in a project cycle about resource management, to identify key opportunities. Furthermore materials and product life cycle need to be examined in order to inform the design decision making process. In this way, RUFUS has highlighted the opportunity to innovate when applying early thinking of efficiency and resource management to reduce the project impacts.

Another way to enhance resource management in geotechnical engineering is to maximise recycled content of projects. By increasing the use of recycled materials, many natural resources such as virgin aggregates and water can be saved reducing the impacts on the environment. An example of this approach in geotechnical research can be seen in Serridge, 2007 and Tranter *et al.*, 2008. In these specific research projects, recycled materials are used to produce recycled aggregate for vibro-stone columns.

Resource management is an important requirement to improve sustainability in geotechnical projects. Moreover this subject cuts across many different geotechnical issues encompassing broader concepts such as whole life cycle, value for money, good management (up and down the supply chain) and innovation. However, to make the most of this approach, it is crucial to look at it in a holistic context considering social, environmental and economic impacts as well. This is still missing in the literature and geotechnical research.

3.4: The way forward for geotechnical research

While current researchers in geotechnical engineering have improved and permitted positive developments for geotechnical projects, so far there is still no holistic established approach to assess and embed sustainability in geotechnical projects. This is because there is still a lack of research about sustainable tools that aid geotechnical designers, informing and supporting holistic choices about environmental, social and economic effects of projects. In addition the available research in sustainability is very specific to isolated subjects such as resource efficiency. This lack of holistic approach for geotechnical engineering is a barrier to the advancement of the sustainable agenda, which prioritises a balance between all the pillars of sustainable development.

In this context, geotechnical engineering research has a crucial role in moving forward and developing ways to aid geotechnical designers to shape and achieve the sustainability credentials of a project. However, to achieve this requires a shift in the focus from technical and sometimes environmental to better encompasses sustainable geotechnical practices.

This would enhance sustainability and reduce impacts at the point in a construction project when some of the greatest gains can be made to improve and sustain the built and natural environment and subsequently improve quality of life of society (Jefferis, 2005; Jefferis, 2008).

Therefore, there is still a strong demand to change the focus in geotechnical design towards sustainability. This manifests itself as a need for sustainability assessment systems focused on the embedment of sustainability into the geotechnical process.

CHAPTER 4: Assessment of Sustainable Development

Fundamental to improve sustainability is the need to identify, qualify and quantify all aspects of a project. Therefore to enhance the embedment of sustainable values in all areas of construction, including geotechnical engineering, a suitable set of indicators and systems to assess sustainability is needs to be developed. This is to provide guidance to designers and to a lesser extent to contractors, and to help the propagation of sustainable practices.

4.1: Sustainability indicators

Even though sustainability cannot be defined objectively and unambiguously measurement is still required. To understand this paradigm, many researchers have over the last two decades attempted to evolve indicators for implementing sustainable development, evaluate progress made and to illustrate concepts and parameters involved (Rey-Valette *et al.*, 2007).

Although, sustainability is essentially about the quality and other intangible non-physical aspects of life, this does not mean that it is not possible to derive measures for them. Limiting aspects of sustainability (such as the sustainable productive capacity of a specific area of land, or the carrying capacity of the world), and trends in the direction of sustainability (such as greater use of public transport, more equitable distribution of income) can and be evaluated. From this it is possible to choose indicators that are appropriate and meaningful to represent the aspects that need to be measured and evaluated (Fricker, 2001).

In this context two possible ways of measurement are possible. The first is to provide thresholds, below which an unsustainable state is entered. The second way is to provide directions in which changes need to be made in order to achieve goals of sustainability (Fricker, 2001).

Therefore the main value of sustainability indicators is in indicating direction of change instead of desirable state. Indicators are different from data or statistics in the sense that they provide meaning beyond the attributes directly associated with them and thus provide a bridge between detailed data and interpreted information (UN, 2010).

Thus, the main function of an indicator should be to help decision-makers to understand where they are, which way they are going and how far they are from where they would like to be. Sustainability indicators will intend to show how much progress has been made towards achieving sustainability and they will allow decision makers to identify areas in need of improvement. A sustainability indicator can represent standards for measuring criteria (conditions) of sustainability and they can be as varied as the systems they monitor. Indicators of sustainability should provide directions and point to areas where the links between the economy, environment and society are important (Flint, 2004). Concisely, sustainable indicators need to make information meaningful and actionable.

4.2: Limitations of indicators of sustainability

It should be acknowledged that there are limitations for sustainability indicators and this is a point of scientific controversy present in the contemporary debate about sustainable assessment (Munda, 2003). Controversy could appear while choosing and using sustainability indicators, a key difficulty being that of subjectivity. Subjectivity enters in two fields: on the selection of the indicators and on the evaluation of the indicators results (Farsari and Prastacos, 2002).

Primarily indicators are chosen by people with specific knowledge and from certain scientific and social backgrounds (Meadows, 1998). Thus a certain degree of subjectivity is inevitable (Bossel, 1999). Other problems include lack of appropriate data, which may result in vital information being missing. This could further lead to measuring what is measurable rather than what is important (Meadows, 1998; Farsari and Prastacos, 2002).

Thus, the basis of sustainability measurement may be subject to bias and change, without a strong scientific foundation. Therefore if indicators are not chosen carefully and as systematically as possible they will carry the wrong message resulting in misleading and inappropriate conclusions (Farsari and Prastacos, 2002). However these limitations should not be used as an excuse not to develop systems and methodologies to evaluate sustainability. Instead these difficulties should be an incentive to move research forwards into developing new reliable sustainable indicators whenever suitable and necessary.

4.3: Sustainable indicators for construction and geotechnical engineering

Measurement is fundamental to progress as it is important to recognise and learn from changes that have been implemented (CIOB, 2001). In line with this concept, indicators to measure or evaluate sustainability throughout the construction industry (from master planning to actual construction) are essential to provide guidance on how to evaluate the impacts and effects of the industry at social, environmental and economical levels.

Sustainability indictors for construction are complex and can be dependent on the level of activity to be measured or evaluated. Due to the interdependence between the different sectors of the construction industry (as shown in the Figure 2.3 Chapter 2) indicators for construction can also be divided in two levels, macro and micro indicators.

While these levels appear to be different, they are actually interdependent and complement one another since there are many overlapping issues between them. For example, requirement for planning permission to build a zero carbon building (master planning/macro decision) would cause the architects, structural engineers, geotechnical engineers and other professional (sub-layers of construction industry /micro decisions) involved in design and construction to act upon this direction in turn to deliver an end product according to the specification set by the client. However to enable sub-layers to deliver the desired macro results it is necessary to have in place micro indicators to enable professionals at all levels to understand and to evaluate the impacts and effects of their decisions and practices. Thus, given the individuality of every sector of the industry, some bespoke indicators are needed to better assess specific issues related to each field.

To date, not every field of construction has developed its own sustainability indicators. Thus in many ways it is still a challenge to identify the hidden weaknesses when attempting to embed sustainability throughout the construction industry processes. Some sustainability assessment systems developed for master planning have assumed that macro indicators will pick up micro aspects elsewhere (e.g. Hillier *et al.,* 2005 Jefferson *et al.,* 2007; Harbottle *et al.,* 2008) but this has caused confusion and consequently poor adoption of sustainability across all areas of construction.

Therefore currently in the construction industry, there is room and need to develop (or adjust) sustainability indicators for each link of the construction chain. These micro indicators, if developed by specialists of their discipline in partnership with sustainability consultants, would allow the unique practicalities of each sub-sector of the construction industry to understand and agree upon benchmarks to provide guidance towards sustainable development.

Moreover, the practical implementation of sustainability values into many levels of construction still varies according to the state of development of micro indicators for each sector and the availability of systems to make the best use of these indicators. Thus, to evolve in disseminating sustainability values and making practical the assessment of the sustainability of projects, sustainability indicators for all levels of construction are fundamental.

4.4: Assessment systems for sustainability

While there are still many definitions of SD, there are equally as many ways of measuring it throughout the application of various sustainability indicators systems (Hunt *et al.,* 2008).

Sustainability indicators systems are composed of combinations of economic, environmental and social indicators carefully arranged accordingly to the need of the activity to be assessed.

Modern assessment systems for SD have come a long way in the last few decades and several methodologies have been developed to assess sustainability, or parts of it (one of the three pillars separately) within organisations, projects and products (Kapelan *et al.,* 2005). However most systems opted not to assess sustainability as a whole due to the complex trade-offs between social, environmental and economic aspects that sustainable development demands due to this involving several different scales simultaneously.

Trade-offs can take place either in the space (between losses in natural capital or some other measure here and gain somewhere else) or in time (between losses or gains now and those coming in the future). In addition there can be difficult choices between natural and human-made capital or between social, environmental and economic dimensions of development. Principles of inter-and intra-generation equity demands that balance be struck between the need of present and future generations.

Facing this complexity in evaluating the trade-offs between the different pillars of SD in time and space, most organisations concerned about economic, social and environmental responsibilities in the context of sustainable development decided to develop separated systems to assess their performance and accountability in these areas. Examples of well-established systems that evaluate isolated areas of the sustainability of a project, a product or a company are the environmental management systems (EMS) and the corporate social responsibility systems (CSR).

In general there remains confusion about the difference between environmental management systems, corporate social responsibility and sustainability (Braithwaite, 2007). In this way, to the present, there is still a lack of clarity about how to choose a sustainability assessment system and what they actually measure (see Table 4.1 for more information about EMS and CSR).

Table 4.1: EMS and CSR systems overview (Braithwaite, 2007)

System: Environmental Management Systems (EMS)

Description: EMSs are probably the most well-established assessment approaches for environmental assessment. The main aim of an EMS is to focus on improving environmental performance over the time and compliance with legislation. There are three recognised standards or schemes: (a) ISO 14001 is the international standard for EMS which specifies the features and requirements necessary to help organisations systematically identify, evaluate, manage and improve the environmental impacts of their activities, products and services.

(b) EMAS (the European Union Eco Management and Audit Scheme) is a voluntary EU-wide scheme that requires organizations to produce a public statement about their performance focused on legislative compliance and includes ISO 14001 as the requirement EMS component.

(c) BS 8555 is recent addition to the EMS family and breaks down the implementation process for ISO 14001 or EMAS into six stages. The Institute of Environmental Management and Assessment has developed the Acon Inspection Scheme which enables companies to gain accredited inspection and recognition for their achievements at each step as they work towards ISO 14001 or EMAS.

Comment: Critics against EMS argue that the system has become very demanding in terms of paperwork, reporting and document-handling to ensure compliance with legislation and the relevant standards. In this way, although the system it is useful and can help organisations to improve their resource efficiency and costs reduction, the system does not properly address social aspects of sustainability.

Table 4.1: EMS and CSR systems overview (Braithwaite, 2007)

System: Corporate Social Responsibility (CSR)

Description: CSR is best known for being one of the series of growing annual reporting documents that large organisations produce. CSR relates to the quality of management, of both people and process, and the nature and quality of the organisation's impact on society within the areas it operates.

The World Business Council for Sustainable Development (WBCSD) defines CSR as 'the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large'. While CSR tends to be perceived differently throughout the world, the European model focuses on operating the core business in socially responsible way, complemented by investment in communities for solid business case reasons.

There are a number of high-profile CSR-related assessments systems such as FTE4Good, Dow Jones Sustainability Index (DJSI) and Global Reporting Initiative (GRI) which are self-certified award-based systems centred on predetermined criteria and weightings. The UK government supports the best-practice programme led by Business in the Community, including their Corporate Responsibility Index (CRI). CRI is business led, voluntary and, once again, self-assessed. CRI was developed in consultation with more than 80 businesses and key stakeholders. CRI covers key risks and opportunities in the areas of community, environment, marketplace and workplace.

Comments: CSR relates much closer to assessing the sustainable performance of an organization; however, the system can be time consuming and thus expensive. Critics of CSR argue that the system is very time-consuming and designed in a way that most of the time is spent collecting data instead of coming up with new ways to improve business practice. Also, CSR reporting can be a very expensive backwards-looking assessment of what has been done in relation to set criteria rather than a performance framework that allows the organisation to look forwards.

Thus, the main argument against these both systems is the fact that they do not assess the all three aspects of SD simultaneously. Also they are based on introducing administrative systems or completing extensive assessments, which include pre-determined weighting systems. Moreover, they are both designed in a way that the assessors are driven to achieve some form of recognition, an award or privileged listing, instead of pursuing actual improvement. As such, this produces a bias towards achieving better results where the reward and best score of the tool in question are focused.

Looking at the weaknesses of EMS and CSR in terms of promoting sustainable development many organisations decided to develop complementary frameworks to address sustainability as a whole. Thus, bespoke systems have been developed over and over again by different industries and organisations in an attempt to create innovative assessment systems. However, the overdevelopment of tools generated confusion and tool fatigue (Walton *et al.*, 2005).

To date there is no well-established system to address the whole sustainability of organizations, projects and products. There are however, several non-established tools available to assess sustainability or parts of it. Therefore the tool landscape is complex and confused and there is still a need to be optimised in order to facilitate the assessment and embedment of sustainability into business in general.

In this way, the development of yet another tool should be avoided and opportunities in reviewing current assessment systems and adjusting existing methodologies should be explored. This is to evolve available tools, make the most of available knowledge and research and optimise the tool scenario at the same time.

4.5: Assessment systems for sustainability in construction and civil engineering

There is general agreement that in order to embed sustainability into construction projects a common model for sustainable construction needs to be agreed and indicators, and systems, need to be in place to set targets enabling measurement of sustainability in the industry. (Watson and Zakri, 2009) However there is still a lack of consensus on a definition for sustainable development in relation to the built environment. Thus, organisations within the construction industry have produced their own different guidance documents and / or tools to assist practitioners in implementing sustainable development. (Arup, 2007)

To date a large number of tools, guides, systems and approaches are available to assist the mainstreaming of sustainability into macro level of construction and civil engineering projects. Table 4.2 describe some of the more common and widely used systems which assess sustainability in construction projects.

BREEAM	Table 4:2 Common and widely environmental/ sustainability assessment systems for construction
(Building Research Establishment Environmental Assessment Method) Use : Mixed Use Development Developed by: BRE (Building Research Establishment)	The BRE's Environmental Assessment Method (BREEAM) is a system for measuring the environmental performance of new and existing buildings. In addition to Bespoke BREEAM, there are several other versions of BREEAM each designed to assess a particular type of building, Buildings are assessed and awarded credits according to the level of performance within a range of 9 environmental categories. The credits are then added together using a set of environmental weightings to produce a single overall score. The building is then rated on a scale of PASS, GOOD, VERY GOOD, EXCELLENT and OUTSTANDING and a certificate is awarded that can be used for promotional purposes. BREEAM assesses the performance of buildings in the following areas: Management, Energy use, Health and Well-Being, Pollution, Transport, Land Use, Ecology, Materials and Water. BREEAM 2008, the latest update includes major changes from the previous versions including a new rating level of BREEAM Outstanding (BRE, 2010)

CEEQUAL (Civil Engineering Environmental Quality Award Scheme) Use: Civil Engineering Projects Developed by: team led by the UK Institution of Civil Engineers	The Civil Engineering Environmental Quality Award Scheme (CEEQUAL) was developed by a team led by the UK Institution of Civil Engineers. It assesses the environmental performance of civil engineering projects, including roads, railways; airports; coast, canal and river works; water supply and wastewater treatment; power stations; retail and business parks. CEEQUAL has five different awards categories: Whole Project Award; Client and Design Award; Design Only Award; Construction Only Award and Design and Build Award. In these awards performance is rated in 12 subjects with credits or points being awarded to reflect their significance to the CEEQUAL assessment to produce a single overall score. The performance is then rated on a scale of PASS, GOOD, VERY GOOD or EXCELLENT and a certificate is awarded that can be used for promotional purposes. CEEQUAL scores are distribute across the following subjects: Project environmental management; Land use; Landscape; Ecology and biodiversity; Archaeology and cultural heritage; Water; Energy; Use of materials; Waste; Transport ; Nuisance to neighbours and Community relations. It should be noted that a 100% score in the CEEQUAL assessment is not possible. There are issues that conflict with each other, and a high score on one aspect may mean that points will not be scored on other aspects. (CEEQUAL, 2008)

DQI (Design Quality Indicators) Use: All types of construction projects Developed by: Construction Industry Council	The DQI was launched in 2002. The development was led by CIC (Construction Industry Council) with sponsorship and support from many government and industry bodies. Involved parties include the Department for Business, Enterprise and Regulatory Reform (BERR), the Commission for Architecture and the Built Environment (CABE), Constructing Excellence, the Office of Government Commerce (OGC), and the Strategic Forum for Construction (SFfC). Although the system is not designed to assess sustainability, its indicator's assess many social and environmental issues helping designers to improve areas of sustainability. It can be used for new buildings and refurbishments of police stations, office buildings, educational buildings, libraries, and many other civic and private building projects. DQI applies an assessment approach based on the model by the engineer Vitruvius, the Roman author of the earliest surviving theoretical treatise on building in Western culture, who described design in terms of utilitas, firmitas and venustas, often translated as commodity, firmness and delight. • Functionality (utilitas) - the arrangement, quality and interrelationship of spaces. • Build Quality (firmitas) - the engineering performance of the building. • Impact (venustas) - the building's ability to create a sense of place and having positive effect on the community and environment.

Regional Sustainability Checklist for Developers Use: All types of construction projects Developed by: BRE	The Regional Sustainability Checklist for Developers was developed by the Building Research Establishment (BRE) and provides a practical framework to measure the masterplan sustainability of developments (both buildings and infrastructure) at site or estate level. The Checklist sets out a range of questions addressing key sustainability issues, and provides technically sound markers for “good” and “best” practice. Answers are scored and cumulative scores weighted to provide an overall indication of the sustainability of the development. The Regional Checklist incorporates regional planning, sustainable development and other key policies and targets into the tool. Reference is made to sources of further regional and national information. Key local and regional stakeholders are invited to form an advisory group to ensure that relevant issues are taken into account. Furthermore, the checklist provides a common framework for discussions between developers, local authorities and communities. The checklist embraces a wide range of indicators from natural resources to energy, impact on individual buildings, ecology and the community. (BRE, 2010 $_2$)

ENVEST 2 Use: All types of construction projects Developed by: BRE	Envest 2 allows both environmental and financial tradeoffs to be made explicit in the design process, allowing the client to optimise the best value according to their own priorities. On Envest 2 designers input their building information (height, number of storeys, window area, etc) and choices of elements (external wall, roof covering, etc) and the system identifies those elements with the most influence on the building's environmental impact and whole life cost and shows the effects of selecting different materials. It also predicts the environmental and cost impact of various strategies for heating, cooling and operating a building. Environmental data may be presented as a range of 12 impacts, from climate change to toxicity, as well as a single Ecopoint score, for ease of communication, especially in comparison with costs. Envest 2 is web based, allowing large design companies to store and share information in a controlled way, enabling in-house benchmarking and design comparison. Two versions of the tool are available: • Envest 2 estimator uses default environmental and financial data about the whole life performance of the building. • Envest 2 calculator provides default environmental data but allows the user to enter their own capital and lifetime financial cost information. (BRE, 2010_3)

LEED (Leadership in Energy & Environmental Design) Use: Buildings and Communities Created by: Green Building	LEED is a third-party certification program and a benchmark for the design, construction and operation of high-performance green buildings. LEED provides a set of indicators to measure impact of buildings' performance. LEED rating systems are developed through an open, consensus-based process led by LEED Committees. Each volunteer committee is composed of a diverse group of practitioners and experts representing a cross-section of the building and construction industry. LEED has several rating systems assessing: New Construction; Existing Building; Commercial Interior, Core and Shell, Schools, Retail, Health Care and Neighbourhood Development. These systems recognise performance in five key areas: • Sustainable site development • Water savings • Energy efficiency • Materials selection • Indoor environmental quality LEED is a Global scheme and is currently in use in more than 30 countries. (Green Building, 2010)

SPeAR® (Sustainable Project Appraisal Routine) Use: All types of construction projects Developed by: Arup	SPeAR® is a software system developed by Arup to evaluate the sustainability of construction projects. SPeAR® contains a set of core sectors and indicators that have been derived from a large literature on sustainability. The system evaluates sustainability performance measures, using a four-quadrant model that focuses on the key elements of environmental protection, social equity, economic viability and efficient use of natural resources. The software is however capable of including indicators that reflect the context and scope of the project and so create a bespoke appraisal. The appraisal is based on the performance of each indicator against a scale of best and worst cases. Each indicator scenario is aggregated into the relevant sector and the average performance of each sector is then transferred onto the SPeAR® diagram. The methodology behind the SPeAR® diagram ensures that all scoring decisions are fully audit traceable; and the diagram provides a unique profile of performance, highlighting both strengths and weaknesses from the perspective of sustainability. (Arup, 2007) SPeAR is available free free-of-charge to students and educational establishments solely for teaching and research purposes.

Code for Sustainable Homes Use: Homes Developed by: UK Government, CIRIA and BRE	The Code for Sustainable Homes has been developed to enable a step change in sustainable building practice for new homes. It has been prepared by the Government in close working consultation with the Building Research Establishment (BRE) and Construction Industry Research and Information Association (CIRIA), and through consultation with a Senior Steering Group consisting of Government, industry and NGO representatives. The Code is intended as a single national standard to guide industry in the design and construction of sustainable homes. It is a means of driving continuous improvement, greater innovation and exemplary achievement in sustainable home building. The Code will complement the system of Energy Performance Certificates which is being introduced in June 2007 under the Energy Performance of Buildings Directive (EPBD). The EPBD will require that all new homes (and in due course other homes, when they are sold or leased) have an Energy Performance Certificate providing key information about the energy efficiency/ carbon performance of the home. Energy assessment under the Code will use the same calculation methodology therefore avoiding the need for duplication. (BRE, 2010_4)

As can be seen from Table 4.2 most of the systems evaluate different areas of sustainability separately. However very few systems attempt to assess holistically the three aspects: social, environmental and economic.

To date, the majority of the systems described in Table 4.2 claim to assess SD in construction / civil engineering, but in reality most of them are still predominately environmentally focused and fail to provide the holistic coverage needed to fully assess sustainability, for example BREEAM and CEEQUAL (further discussion is provided in Chapter 5).

However, to address the various technical, social, economic, environmental and regulatory issues an ideal assessment system for SD should have as wide a range as possible of sustainable indicators well balanced between three pillars - social, environmental and economical. Thus there is growing literature calling on assessment systems that cover all aspects of sustainability and not just environmental aspects (Parkin *et al.*, 2003; Walton *et al.*, 2005; Braithwaite 2007; Hurley *et al.*, 2008; Elghali *et al.*, 2008).

This is because over the last decade the understanding or interpretation of sustainability in construction has changed. Initially the emphasis was on how to deal with the issue of limited resources, especially energy, and how to reduce the impact of the natural environment (CIB, 1999). Now, the current significance of a holistic approach considering social, economical and environmental issues has broadened the view and the understanding of the term sustainable construction. In this way, assessment of sustainability in construction has also changed. Thus most of the systems now available need to be updated to follow these changes and make use of a more holistic approach.

A common criticism of the systems available is that they are designed as checklists, reducing the incentive for professionals to greatly exceed the standard on any particularly item. (Wheeler, 2004) Most importantly very few checklist systems are designed to aid the decision making process of projects from the beginning, when it is most important to identify the environmental, social and economic weakness of a project.

Another limitation of some of the systems available, such as EMS and CSR, is that they are designed to achieve some sort of recognition, award or privilege listing. This if not well managed can become the overriding measure of success for the project rather than an actual vehicle for improvement and successful embedment of sustainability (Braithwaite, 2007).

The singular use of qualitative or quantitative analyses is another constant cause of confusion in using these systems. Complex sustainability issues can be better assessed by linking different qualitative and quantitative methods in methods such multiple-criteria analysis. However to date little has been done to utilise this approach in the construction industry due to its complexity.

Another issue to be overcome is the fact that most systems have assumed that higher-level indicators will pick up lower aspects elsewhere (e.g. Hillier *et al.*, 2005; Jefferson *et al.*, 2007; Harbottle *et al.*, 20008). Higher-level indicators not always are suitable for the more specialised fields of the construction industry, such as geotechnical engineering (this will be further discussed on Chapter 5). However, to date there is a limited number of assessment tools and indicators for sustainability at the lower level of civil engineering. In many cases, such as geotechnical engineering, frameworks are yet not even available (Jefferis, 2008).

Overall, if the true extent of the impact of construction works is to be assessed objectively, a suitable sustainability assessment system is required. This must both feed off, and feed into, the assessment of sustainability at all levels of (re)development – from masterplanning down to geotechnical engineering (and other specialist disciplines) – allowing information flow to take place as seamlessly as possible. Without this interactive approach, many of the trade-offs and quick wins could be lost.

That does not mean the tools available are not useful. There is much to be learnt from these indicator systems. However, there is certainly room for research and improvement to improve these systems.

The use of sustainability assessment tools is still growing worldwide. The broad range of systems available reflects the fact that many organisations understand the importance of assessing SD in construction. The small amount that has been published about the practical use of these systems points to the fact the construction industry has yet to fully understand how to deal with assessment systems in a productive way.

Moreover impracticalities present in current systems have been multiplied over the years. This is because the majority of the newer systems just mirror the previous ones without much research into improving the methodologies. Therefore, to avoid the multiplication and overdevelopment of inappropriate systems further research is needed. This is to understand and overcome the issues, which need to be improved in order to facilitate the practical use of sustainability assessment systems for construction.

In this way it is also important to support the use of a good improved system to establish sustainable assessment practices and facilitate communication. This is with the intention of transforming the current image associated with sustainability tools from endless checklists to design-aiding tools.

Ideally a system should be established to provide real aid to professionals in the construction industry, engaging and challenging professionals to fully assess their activities in a holistic manner from the design stage. This system would help designers to explore desirable and feasible changes as means of achieving a more sustainable outcome.

Chapter 5: Sustainability Assessment for Geotechnical Engineering

As discussed in Chapter 2, the sustainability of a whole construction project depends entirely on the sustainability of its parts. To date several assessment systems have been developed to assess and embed sustainability into some specific high-level fields of the construction and civil engineering industry, but there is still a huge gap in research for lower levels such as geotechnical engineering (see Chapter 4).

5.1: Drive to assess sustainability in geotechnical engineering

However as Governments increase their guidance on how to improve sustainability in communities and raise targets in reduction of carbon emissions, waste and energy consumption in construction (DEFRA, 2009), every link of the construction chain also faces increasing pressure to prioritise sustainability throughout. In this manner, activities such as geotechnical engineering need to raise sustainability performance and level compatible with the high-level sectors, where sustainable values are already successfully being embedded (Jefferis, 2008).

Despite the drive from the industry and the many opportunities for sustainable development to be embedded in geotechnical engineering, specific guidelines are still few and far between. (Jefferis, 2008) To date, very little help is available for geotechnical designers to assess projects and understand where the main changes are needed to be implemented.

As commented in Chapter 3, currently little has been published in consideration of sustainable assessment in respect of geotechnical engineering (Hillier *et al.*, 2005) and thus authors have been calling for more research in this area (e.g. Jefferson *et al.*, 2007; Pediaditi *et al.*, 2006; Dixon *et al.*, 2007; Jefferis 2008).

In the meantime the attempts to develop generic assessment systems for construction and civil engineering, although numerous, have so far been of little practical value for geotechnical engineering. Even more, the few available systems for assessing sustainability in geotechnical engineering (or parts of it) are still very much at research level and thus little is known about the extent of their use.

5.2: Tools for sustainability assessment of geotechnical projects

There are several tools that have been widely mentioned in the available current literature about sustainability / environmental assessment systems. Also there are few examples mentioned on literature about ongoing research projects developing sustainability indicators for specific fields of geotechnical engineering. However there is still no system yet available concerning the whole field of geotechnical engineering that captures micro aspects whilst allowing acknowledgement / assessment of macro level issues to be assessed.

5.2.1: Highways agency sustainable geotechnics – framework arrangement for the geotechnical research & development advice

Hillier (Hillier *et al.,* 2005) produced the Highways Agency Sustainable Geotechnics – Framework Arrangement for Geotechnical Research & Development Advice and was the first public available framework for Geotechnical research for sustainability in the UK.

In this framework Hillier (*et al.,* 2005) suggested that there is no distinct sustainability model (UK or international) applicable to highways geotechnics. The unique controlling influences of highway engineering projects (e.g. route location and selection, geological and topographical conditions, integration with existing infrastructure) require alternative considerations from those for discrete building / construction assessments. Therefore, sustainability assessment for geotechnical aspects of highway infrastructure requires a bespoke system that draws on some aspects from the construction industry standard assessment frameworks (BREEAM, CEEQUAL, KPIs) and methodologies (Life Cycle Assessment, Embodied Energy).

In this study a proposed sustainability assessment methodology for highway geotechnical projects was presented. The main themes considered for assessment where:

- Management of Natural Resources – designing for minimum waste, lean construction, recycling and reuse.
- Reducing Energy Consumption - minimizing energy consumption during construction and use.
- Reducing Emissions - minimising noise and emissions to air, water and ground.
- Landscape, Townscape and Heritage - minimising the visual impact of the network and protecting heritage.
- Biodiversity - protecting the habitats and species on the Highways Agency land alongside the network.
- Respect for People - taking due consideration of the needs of the people employed through the Highways Agency as well as those of its external stakeholders, such as local communities.
- Partnerships for Better Business - taking action to deliver better value services through partnership with suppliers.

The main conclusion of this research was that in order to assess better the sustainability of a highway project there was need to consider a project life cycle from the 'cradle to the grave' of the following five themes:

1. Land take

2. Geotechnical Construction

3. Geotechnical maintenance issues during the life of a highway

4. Highway usage, as affected by geotechnical earthworks design

5. Adaptation and Decommissioning

The report is very environmentally focused and the authors assume that “many of the key financial, economic and social assessments for a proposed scheme will have been developed in detail prior to the ‘geotechnical’ assessment.”

The authors also comment, at the time, that sustainability and environmental awareness were relatively new and emerging subjects, and therefore propose further research.

5.2.2: Environmental Geotechnics Indicators (EGIs)

The EGIs system offers complete flexibility and is made up of 76 generic indicators + 32 additional ‘technology-specific’ indicators (to assess the environmental sustainability of specific techniques for treating contaminated land) derived based on both experience gain from several projects and existing indicators systems (Jefferson *et al.*, 2007). This system breaks a project in eight clear and logical stages that consider the timeline of a project. At each stage the ‘sustainability performance’ of the project can be assed by a manageable set of indicators using a fully quantitative method of analysis. However the system is primarily environmentally focused thus not assessing social and economical areas.

The authors commented that the success of the assessment tool ultimately depends on its widespread acceptance and implementation. Thus incorporation into contracts and perhaps ultimately legislation are ways to embed sustainable values into projects rapidly. As such there is need for more case histories, education of clients and stakeholders, together with the fostering and increasing awareness of sustainability within the construction industry.

5.2.3: Sustainability of land remediation using Multi-Criteria Analysis (MCA)

This methodology was developed for use in contaminated land and land remediation. (Harbottle *et al.,* 2008) This work uses Multi-Criteria Analysis (MCA) to provide both an overall picture and a detailed investigation of the individual impacts of the technical / environmental sustainability of remediation.

MCA is often used in decision-making. MCA is a structured system for ranking alternatives and making selections and decisions. Considerations used in MCA are: how great an effect is (score) and how important it is (weight). MCA describes a system of assigning scores to individual effects (e.g. impact on traffic, human health risk reduction and use of energy). These can then be combined into overall aggregates on the basis of the perceived importance (weighting) of each score. With MCA, ranking and decision-making processes can be made more transparent (Wrisber and Udo de Haes, 2002).

The methodology considers four key criteria:

1. Future benefits outweigh cost of remediation.

2. The environmental impact of the remediation is less that the impact of leaving the land untreated.

3. The environmental impact of bringing about the remediation process is minimal and measurable.

4. The timescale over which the environmental consequences occur, and hence inter generation risk, is part of the decision making process.

Also, Harbottle *et al.* (2008) provide a matrix of relative performance between different remediation strategies. The matrix shows a range of less favourable sustainability issues for each project that may need to be addressed in future projects if sustainability is included in the decision making process. However, the authors commented that the use of qualitative information in the MCA leads to the introduction of subjectivity, both in scoring and in weighting.

5.2.4: Comparison of embodied energy for sustainability assessment of geotechnical structures

Attempts have been made to use LCA as assessment tool to quantify environmental impacts in geotechnical engineering. Chau *et al.* (2008) defends the use of LCA to compare environmental impacts between design options. The argument for the methodology is that by comparing life cycle data of specific environmental indicators (such as CO_2 emissions, water use, waste production and energy consumption) designers are able to make more informed decisions about the relative environmental impacts of their projects and able to avoid unwanted outcomes. However computing the relative environmental performance between projects not necessarily provides a measurement for the relative sustainability performance of the project. Positively, the LCA method is internationally established and accredited by ISO 14000 standards.

A complete LCA consists of four phases: 1) Goal and scope (boundary) definition; 2) Inventory analysis (LCI); 3) Impact assessment (LCIA), and 4) Interpretation/Improvement.

1) Goal and Scope

Defining the purpose is a key first step of an LCA and requires careful consideration of: for whom is the LCA to be carried out and for whom are the results meant; the subject of the study (the functional unit) and the level of detail required. The functional unit is the product which is to be studied. For example, for a geotechnical project the functional unit could be to provide the foundations for a building (especially if the LCA is undertaken by/for geotechnical engineer). The other key steps in goal and scope definition are:

- Definition of the system boundaries;
- Definition of data requirements, including an estimate of the variability associated with the data;
- Assumptions in the study and limitations of the results;
- Identification of impact categories to be analysed;
- Determination of the relevant requirements for reporting and peer review.

The system boundaries define the scope of the study. In sustainability assessments, it will be key to define these boundaries – especially in relation to social impacts but it may be particularly difficult. As a result, system boundaries may end up being influenced by personal preferences rather than purely data considerations.

2) Inventory analysis

This forms the core of LCA and also can form the core of sustainability assessments. For an LCA the process flow chart will define what is being produced and the major materials and emissions flows across the system boundary. For the construction of a foundation pile the process could involve energy inputs for excavation and materials production (e.g. cement production), mining of aggregates for concrete, disposal of material arising from the excavation (these may be used elsewhere in the development and therefore it may be necessary to allocate the environmental burdens between the various components of the development). Data collection is often a major operation though there is now a considerable body of generic data in the literature and databases/software such as Gabi 4 and SimaPro. Processing the data involves converting the gathered data into a convenient form for analysis.

3) Interpreting the results

The first step in interpreting the results requires input on the environmental impacts to be assessed. In LCA there is a developing consensus as to the impacts to be considered. These include parameters such as global warming potential, acidification and photo-oxidant formation. It is important to note that the selection of the list of indicators can influence the outcome of the analysis and thus the geotechnical engineer should carefully consider the indicators used in any sustainability assessment. Once the impacts have been calculated it may be appropriate to normalise them by local, national or world production to give an indicator of relative contribution – though this will not be necessary if the goal of the assessment is comparison of alternative solutions / procedures which perform the same function. If a single score is required, then weightings can be assigned to each of the indicators and the total aggregated to give an overall score. However, it is important to understand that weightings are not absolute but subjective depending on the individual, group, stakeholders, etc. who developed them. They will vary between different peoples and different geographical regions. The degree to which indicators are aggregated should be related to the audience for the results. It may be appropriate to present the same data in different degrees of aggregation within a company, to clients, to project stakeholders, to the local community or to the financial community in a company annual report. All representations will use the same data – the only difference will be the degree of aggregation. However, the greater the degree of aggregation the greater the loss of transparency and the potential for it to be a tool for misinformation. The important point is that the implied sustainability or unsustainability of a project should not change with how the data are presented (Jefferis, 2005).

4) Interpretation/Improvement

The phase stage 'interpretation' is an analysis of the major contributions, sensitivity analysis and uncertainty analysis. This stage leads to the conclusion whether the ambitions from the goal and scope can be met. More importantly: what can be learned from the LCA? All conclusions are drafted during this phase. Sometimes an independent critical review is necessary, especially when comparisons are made that are used in the public domain.

LCA methodology can be used for several alternative uses such as:

- **Full LCA study** – LCA can work hand in hand with Life Cycle Costing and cost benefit analysis
- **Product/material comparison** - LCA can support comparison betweens materials performance and impacts.
- **Carbon footprinting** – LCA can be used for carbon footprint on a number of levels from screening to detailed study.
- **Identification of environmental solutions** – LCA can support comparison between different construction processes such as reuse of foundations and geothermal heating systems.
- **Identification of impacts** – LCA has capability to show high impact areas of the life

cycle of a product (i.e. clinkering in the manufacture of cement)

5.2.5: The Redevelopment Assessment Framework (RAF) for brownfield regeneration

This methodology developed by Pediaditi *et al.*, (2006, see Dixon *et al.*, 2007) has the overall aim to inform stakeholders about the sustainability profile of a site across its life cycle in a way that is practical and integrated within existing Brownfield Regeneration (BR) process. The methodology uses a combination of existing tools to assess different aspects of sustainability of BR projects. It is a process to facilitate use of site-specific sustainability indicators in a participatory manner.

The RAF methodology incorporated six steps:

1. Team build

2. Getting the facts right

3. Preparing the ground

4. Setting priorities

5. Designing the indicators - RAF uses The South East England Development Agency (SEEDA) sustainability checklist and RESCUE (Regeneration of European Sites in Cities and Urban Environments) as support assessments criteria.

6. Putting it all together

This methodology was developed as part of the SUBR:IM research project and has been widely published. However researchers have pointed out that realistically the process could only be applied to large scale developments due to the time and resource implications involved. Furthermore, both planning consultants and Local Authorities officers stated that in order for the RAF to be widely adopted it would have to be stipulated through government guidance or policy. It was also noted that in developments without public-private venture dimensions there might be little incentive for developers to carry out such a process (Pediaditi *et al.*, 2006).

5.2.6: Review of embodied energy in construction of geotechnical highway structures

As further development of the work developed by the Highways Agency in 2005 (Hillier *et al.*, 2005), this research commissioned by the Highways Agency and carried out by Arup developed a practical guide on how to apply Embodied Energy and Carbon Emissions assessment techniques to highways projects (Pantelidou, 2008).

The research involved the development of a quantification tool (spreadsheet) for assessing Embodied Energy and Carbon Emissions to compare different geotechnical structures. This comparison intended to be used as part of a sustainability assessment.

However, the qualitative part of the sustainability assessment was not the subject of this research. The author suggested that this should be looked at within the ‘wider sustainability context’ and potentially explore the impact of all four sustainability sectors: natural resources, environment, societal and economic.

5.2.7: A framework for assessing the sustainability of soil and groundwater remediation

This framework was developed by the UK Sustainable Remediation Forum (SuRF-UK) to help assessors take account of relevant sustainable development criteria in selecting the optimum land-use design, determining remedial objectives for contaminated land and groundwater, and in selecting a remediation strategy and technique. The results were published in March 2010 (SuRF-UK, 2010).

The resulting framework highlights the importance of considering sustainability issues associated with remediation right from the outset of a project and identifies opportunities for considering sustainability at a number of key points in a site's (re)development or risk management process. The framework does not make recommendations on the sustainability of any specific remediation technologies or approaches, but rather provides a framework for assessors to identify the optimum solution on a site-by-site basis.

Further phases of work are planned to develop the indicators for sustainable remediation and demonstrate the application of this framework via a series of worked examples.

5.3: Implications of the assessment of geotechnical engineering

Clearly tailored geotechnical systems (e.g. SuRF-UK, 2010), are still very much under development thus lagging behind the established systems developed for assessment of buildings or civil engineering projects.

In this manner more established generic systems such as LCA and MCA, which apply systemic thinking to impact assessment, have been used to provide useful information to ensure geotechnical engineers are aware of some of the impacts of their projects.

So far, most of the work looking at assessing sustainability/environmental impacts of geotechnical engineering had focused on variations of the life cycle analysis model (LCA) and computing different outcomes of geotechnical processes to determine embodied energy (e.g. Chau *et al.*2008, and Pantelidou, 2008), carbon dioxide (CO_2) emissions (e.g. Dixon and Hall, 2010) and other similar environmental indicators (e.g. Storesund *et al.*, 2008).

However, LCA is a tool traditionally used in assessing environmental impacts and not suitable for assessment of all aspects of sustainability (Sutcliffe *et al.,* 2009). LCA also has some major drawbacks, including the complex and time-consuming nature of the analysis, large data requirements, boundary definition and cost of the analyses.

Moreover, LCA combined with carbon calculation has been increasingly suggested as proxy for the assessment of sustainability with geotechnical projects (e.g. Spaulding *et al.,* 2008). However, this requires a number of assumptions and generalisations in order to achieve values to be used in comparative studies. In addition this focuses on the environmental pillar predominately and so can skew the picture, failing to achieve the core objective of sustainability assessments, namely balance.

Alternative approaches such as Multi-criteria analysis (MCA) can be used when little or no quantitative data are available (Harbottle *et al.,* 2008). MCA is a more flexible system and offers an opportunity to assess complex problems in the face of varying stakeholder opinions. However, there are limitations of applying MCA methods across multiple decision-making scales such as the need to generalise priorities where domain knowledge is relatively high, and the challenges associated with MCA criteria definition. This is because weightings need to be pre-assigned to various factors before the assessment. In a situation where multiple criteria are involved confusion can arise if a logical, well-structured decision-making process is not followed (Hurley *et al.,* 2008).

A more holistic approach such as the RAF model, which uses an existing master plan tool (SEEDA) combined with a geotechnical tool (RESCUE), is very useful in order to demonstrate how to assess high and low level of activities simultaneously. However in the case of the RAF methodology the system is specific designed to focus on just one area of geotechnical engineering (brownfield regeneration) limiting the assessment systems to this sector only.

Therefore, the tool landscape for geotechnical engineering is still very limited without support to geotechnical engineers in assessing the sustainability of projects. So far, the indicator systems available are still bespoke to the specific fields, environmental focus and sometimes have assumed that higher level indicators will pick up other aspects elsewhere (Hillier *et al.,* 2005; Jefferson *et al.,* 2007; Harbottle *et al.,* 2008). Moreover some of these systems have been developed without too much observance to how these would be embedded into the decision making process.

This absent of guidance and assessment tools supports the perpetuation of current practices independently of the sustainability of outcomes. Because of this lack of guidance, designers are constantly in danger of repeatedly making unintended mistakes without understanding where improvements can be made.

Therefore to advance in embedding sustainable values into geotechnical design a key part is to review the current decision making process and develop tools to support it. In order to do that an adequate assessment system by which sustainability can be evaluated and potential sustainability gains can exposed is essential. Nevertheless, currently, there is still no such established system in place to aid geotechnical engineers to understand the concept of SD, establish goals to implementing SD into design and assert the inclusion of the SD values into the geotechnical activities all levels (Abreu *et al.,* 2008; Jefferson *et al.,* 2007; Pediaditi *et al.,* 2006; Dixon *et al.,* 2007).

Thus what is still required to effectively embed the SD values into the geotechnical engineering design, independent of which field, is to develop a strategy to assess and embed sustainability during the whole geotechnical design process. Fenner and Ryce (2008) stated that for a robust assessment framework is an essential component of our ability to deliver engineering sustainability. Without a suitable strategy and framework to guide geotechnical designers, most of the choices made through a design process are still based on budget limitations, previous experience and the engineer's own values and perceptions, which can vary from person to person and company to company.

Therefore, if the true extent of the impact of such geotechnical works is to be assessed objectively a suitable sustainability assessment system is required that can both feed off, and feed into, the assessment of sustainability at all levels from master planning down to geotechnical engineering, allowing information flow to take place as seamlessly as possible.

CHAPTER 6: The Development of a Tool for Geotechnical Engineering Assessment

Currently there are numerous indicator systems that exist within the UK, which can be used to assess a wide range of issues related to SD at differing levels of the construction industry (see Chapter 4). However a specific tool that is relevant to geotechnics has yet to be developed (see Chapter 5).

Of the multitude of tools that do exist, few offer much use for sustainability assessment for geotechnical engineering as they have the common weaknesses discussed in Chapter 4, including the checklist approach, environmental focus and are award focused whilst being impractical for use at the design stages.

Therefore there is a still a need to develop a specific geotechnical system to assess the sustainability of projects and to embed the sustainable values into the design process. As part of this research such a tool will be developed and this chapter describes the process of this development.

6.1: The choice of system

The current tool scenario is already complex and so there is no real need to develop another assessment system to clutter the landscape (Pediaditi *et al.*, in 2006; Dixon *et al.*, 2007). A better alternative is to adapt an existing system to become more geotechnically focused. Moreover if properly adapted some of the established systems have the potential for use in geotechnical engineering, and thus potentially operate across all scales from master planning to a specific discipline focus.

However, master planning systems were originally developed for high-level decision assessment and support, and were therefore not seen to be appropriate to a meaningful geotechnical assessment. When discussed in peer review with geotechnical engineers as possible tools to aid geotechnical design they were immediately labeled as 'sustainability tools' rather than 'geotechnical tools'.

In this way, in order to assess the likely future requirements for development of these tools for geotechnical assessment, four systems were carefully evaluated and the individual strengths and weaknesses were identified (BREEAM, CEEQUAL, LEED and SPeAR®). These industry standard assessment frameworks provide established and recognised models for the UK construction industry to assess sustainability and parts of sustainability in construction projects (Pantelidou, 2008). Also, these four systems are internationally recognised by the construction industry and together several thousands of projects have acquired ratings with these systems around the world (Braithwaite, 2007; Zavrl *et al.*, 2009; Bargwanna, 2009). SPeAR®, although not as established as BREEAM, LEED and CEEQUAL, has been used by Arup on thousands projects including major developments such as the Chongming Dongtan City development and the National Aquatics Center in Beijing. Increasingly this tool is being used to supply project planning and management guidance as well as to influence the design process toward sustainability (Greenline, 2010).

Table 6.1: Evaluated tools overview		
System	**Strengths**	**Weaknesses**
Sustainable Project Appraisal Routine (SPeAR®)	The main strength of SPeAR® is that the system is holistic and evaluates social, environmental and economic aspects simultaneously. Also, the SPeAR® methodology is flexible and allows the exclusion and inclusion of indicators. This flexibility allows the systems to be adapted for different sectors of the construction industry including geotechnical engineering. SPeAR® also has timeline and size flexibility which allows the assessment to be made for different stages of the project (design, construction, use) and for any size of project. The way in which SPeAR® presents the outcomes of the assessment (graphically in a colourful diagram) provides an easy understanding of the weakness and strengths of the project. Moreover SPeAR® is not an awards scheme based assessment.	The main weakness of SPeAR® is the oversimplification of the score system. This characteristic which gives flexibility to the framework is also responsible for creating opportunity for the system to be misused. From a geotechnical point of view SPeAR® indicators are very broad and designed to assess master planning. In this way adjustments of the indicators would be necessary if the systems would be used for geotechnical assessment.

System	Strengths	Weaknesses
BREEAM	BREEAM is becoming widely accepted and well used in the UK. (Hunt *et al*., 2008) In addition the UK Government has been using BREEAM as a requirement for building refurbishment and development which therefore establishes the systems and makes it widely used. BREEAM has different assessment systems for different types of projects. Moreover a bespoke BREEAM can be developed if the project does not fit in an existing category. This provides flexibility to the system and allows geotechnical projects to be assessed with BREEAM.	Although BREEAM is an established tool for environmental assessment of buildings, its indicators are not always suitable for other construction projects. Moreover, BREEAM is an environmentally focused system, including very few social indicators in the assessment systems. Therefore it is not suitable for holistic sustainable assessment. The system is also award focused which can drive designers to strive to achieve scores instead of pursuing actual improvement. From a geotechnical point of view, BREEAM indicators are not easily linked to geotechnical assessment because of the building focus. However, in accordance with the BREEAM methodology a BREEAM bespoke assessment could be developed individually for a geotechnical assessment if commissioned. However to develop a BREEAM bespoke assessment can be costly.

System	Strengths	Weaknesses
LEED	The main advantage of LEED it is the widespread acceptance of this system worldwide. LEED is currently established in several countries including developing countries such as China and Brazil. Comparing the numbers of certified commercial buildings in the UK and the US, it is apparent that despite BREEAM's head start, the number of LEED certified buildings in the US has now surpassed the number of BREAAM certified buildings in the UK. This widespread acceptance helps designers to understand better what is expected of them generally and helps with communication between clients, designers, contractors and suppliers.	In the same way as BREEAM the system was developed to assess only buildings, and is therefore not always suitable to other types of construction projects. Moreover the system is also environmentally focused with very few social indicators. Currently the system is still very much focused on the assessment of energy, water and materials use. This is because originally the system was developed to only assess the energy efficiency of buildings and later on it was enhanced to assess other environmental indicators. LEED is also award focused which can drive designers to strive to achieve scores instead of pursuing actual improvement. From a geotechnical point of view LEED in the same way as BREEAM is not easily linked to geotechnical assessment because of the building focus. However, with the LEED methodology, the system could be used to assess geotechnical projects, which are part of a building project such as foundations.

System	Strengths	Weaknesses
CEEQUAL	The CEEQUAL methodology has been, and continues to be, used successfully on many civil engineering projects throughout the UK. The system will be launched internationally soon (data from May 2010). ICE, BRE and CIRIA developed the system in association with each other and this strong partnership has helped the system to become a reference of environmental achievement within the civil engineering industry. The system is suitable to assess all types of civil engineering projects including geotechnical projects. The unique focus of the system in civil engineering is a great differentiator from other established systems and advantage for using it to assess geotechnical engineering.	CEEQUAL is environmentally focused with the majority of indicators considering only environmental issues. However CEEQUAL also assesses issues such as nuisance to neighbors and community relations that may be regarded as social issues, and some such as Energy, Materials and Waste that can significantly influence the financial outcome of a project. However, the system is not balanced between the three pillars of sustainability. Also, in the same way as BREEAM, and LEED, CEEQUAL is award focused and does not necessarily incentivise designers to focus on actual improvement. From the geotechnical point of view CEEQUAL indicators are suitability for environmental geotechnical assessment but not suitable for a holistic sustainable approach. In order to make CEEQUAL a balanced sustainability assessment, complementary indicators would need to be developed and inserted to address more social and economical aspects.

For all of these tools, further development is needed to adapt them for the purpose of proper assessment of geotechnical projects. Different aspects would need to be changed in order to adapt each indicator for a geotechnical assessment tool.

BREEAM and LEED are environmental and building orientated systems, thus to adapt both tools for geotechnical assessment indicators would need to be revised and created in order to balance social, environmental and economic aspects and address geotechnical specific issues. However the methodology of both systems is award orientated and this could not be changed without major changes to the structure of the tool.

The CEEQUAL civil engineering focus is very suitable for geotechnical assessment. However CEEQUAL indicators are also focused on environmental issues, whilst only touching in a limited way on social and economical aspects. Thus, social and economic indicators would need to be added to the indicator's list in order to create a more holistic framework balancing all three aspects of sustainability. Moreover, like BREEAM and LEED, CEEQUAL is also award orientated and this could not be changed without major changes to the system.

At their heart, CEEQUAL, BREEAM and LEED have their concept of measuring, in some way, the performance of a "prepared design solution", with the expectation that enhancements might then be engineered. In addition these existing tools are heavily skewed towards the consideration of environmental sustainability (Price *et al*., 2009).

In some way, these tools are focused on measuring primarily environmental technical outputs, rather than genuine embedment of sustainability principles into the conception of projects and the formulation of solutions from the earliest stages. This has supported a culture of award points chasing and the checklist approach. For example the use of recycled materials is pursued from the perspective of achieving scoring credits, i.e. the commonly asked question is "What %" must be achieved to give a particular score? Because such scoring systems have to be generally valid they do not promote a culture of embedment, which would explore a more open question along the lines of just "what are the opportunities for resource reuse on this project (Price *et al.*, 2009)?"

Therefore to use one of these systems for assessment of geotechnical projects and embedment of sustainability values into the design process this failure in approach would need to be addressed and the whole structure of the systems would need to change.

However, SPeAR®, in contrast to the other systems, uses the technique of Appreciative Inquire to stimulate the thinking of the designers rather than directing the outcomes of the project. The technique of Appreciative Inquiry was developed in the 1970s at the Case Western Reserve University USA by David Cooperider (Gervase, 1995). Originally developed for change management within organisations the technique has now been applied in a variety of other areas. Appreciative Inquiry is described as "a way of seeing, thinking, acting for powerful, purposeful change" (Price *et al.*, 2009). Moreover SPeAR® allows holistically assessment of social, environmental and economic aspects equally. This provides a more balanced framework for sustainability assessment.

However SPeAR® indicators are orientated at a very high-level and some are therefore unsuitable for geotechnical assessment. Thus to adapt SPeAR® for geotechnical assessment, indicators would need to be revised and possibly complemented. Also the SPeAR® qualitative framework leaves room for the misuse of the scoring system and in order to make the system more transparent some sort of qualitative analysis would need to be introduced to the framework.

In this way, any of these tools could be adjusted for geotechnical use if they were sufficiently adapted. However for the development of this research SPeAR® was chosen as the base for the new geotechnical assessment methodology. This is because of two main reasons that allow changes to the systems without major changes to the framework. First, its holistic approach provides overarching selection of indicators to assess all areas of sustainability.

Second, SPeAR® is not a reward driven system and uses the Appreciative Inquiry methodology, which is flexible and promotes a culture of embedment of sustainable values rather than a culture of points chasing.

6.2: How SPeAR® works in detail

SPeAR® is a tool/software developed for Arup with the aim of making sustainability meaningful to a wide range of stakeholders. The assessment system is developed to demonstrate the sustainability of a project, process or product to be used either as a management information tool or as part of a design process. The methodology is based on a four-quadrant model that structures the issues of sustainability into a framework, from which an appraisal of performance can be undertaken.

The four-quadrant model framework has its origin in the recognition of the linkages between economic, social and environmental systems. This model provides a comprehensive description of sustainability and captures the need for environmental protection, social equality, economic vitality and efficient use of natural resources in every project, process and product if these are to respond to the sustainability agenda (Braithwaite, 2007). The framework highlights strengths and weakness of design bringing this into the decision-making process. This allows continual improvement in sustainability performance and assists in understanding and delivering sustainable objectives.

The tool is founded on the UK Government’s set of sustainability indicators, the United Nations Environmental Programme indicators and the Global Reporting Initiative indicators. The system contains a set of core sectors and indicators that have been derived from the literature on sustainability. However given that sustainability is a flexible concept and is continually changing the software is capable of including and excluding indicators in order to better reflect the current context and scope of the project and so create an up to date appraisal. The actual appraisal is based on the performance of each indicator against a scale of best and worst cases and each indicator scenario is aggregated into the relevant sector. Best and worst cases are part of the set of indicators within the system, however as legislation and best practices change, these indicators are continuously revised. The average performance of each sector is then transferred into the SPeAR® diagram. The spreadsheet behind the production of SPeAR® diagram ensures that the assessment is fully tractable and can be revised or improved at any time (Arup, 2007).

The final diagram illustrates the performance of groups of indicators by shading in a segment on the face. The closer that segment is to the centre of the diagram the stronger it is in terms of sustainability: conversely the further away it is from the centre, the weaker this becomes. The diagram can be compared to a dartboard, with the aim being to have as many segments as possible close to the centre (Braithwaite, 2007).

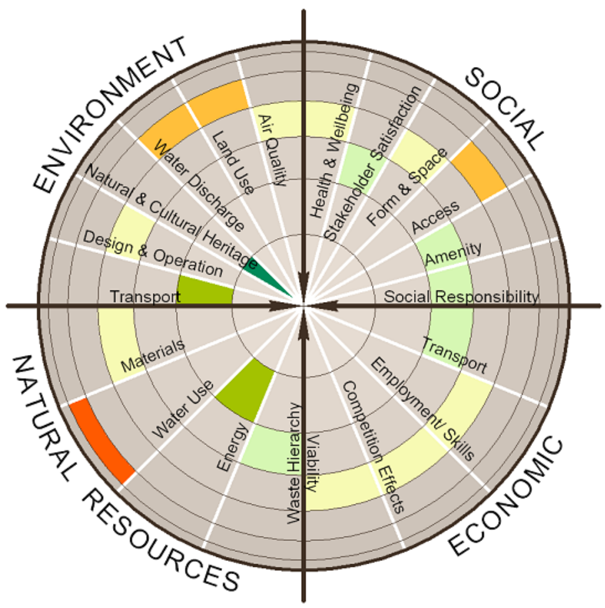


Figure 6.1: SPeAR® four quadrant model (Arup, 2007).

SPeAR® has particular application where responding to sustainability objectives is an imperative. The methodology assists in setting sustainability objectives, tracking the sustainability of a project through its life cycle and assessing alternatives where a decision is to be supported. The model has been applied to a range of projects within a range of sectors. To date the appraisal has been undertaken for urban regeneration schemes, development plans, manufacturing processes and products and has also been used to support a strategy formulation process (Arup, 2007).

6.3: Adapting SPeAR® for geotechnical assessment

A detailed study of the system was undertaken in order to understand better the system and also to review the advantages and disadvantages of the system when in use for geotechnical assessment (Table 6.2). This study involved gathering information about the system, its background and examples of use as well as training at Arup in order to learn how to use the system practically.

Subsequently advantages and disadvantages of the systems for geotechnical assessment were identified.

Table 6.2: Advantages and disadvantages of SPeAR® for geotechnical assessment
a) Advantages
Individual approach: SPeAR® considers each project as unique and compares the different options within a project instead of comparing different projects against each other. This is a key advantage of the system because different projects will have different social, environmental and economic values to society which are difficult to define and evaluate.

a) Advantages
It is not an award scheme: SPeAR® highlights the opportunities and weakness of a design option, but it is not an award scheme to obtain a certain number of points. SPeAR® assessment methodology is based on the techniques of Appreciative Inquiry, to stimulate the thinking of the design team, driving embedment of sustainability values.
Flexibility: The SPeAR® has a flexible structure allowing the exclusion of irrelevant indicators for geotechnical engineering and the inclusion of more relevant ones. The system also provides the opportunity for constant actualization of best and worst cases within the indicators. SPeAR also has timeline and size flexibility which allows the assessment to be made for different stages of the project and for any size of project.
Illustrative framework: The SPeAR® diagram allows the sustainability of a project to be illustrated graphically. The way in which SPeAR® presents the outcomes of the assessment (graphically in a colorful diagram) provides an easy understanding of the weakness and strengths of the project in each evaluated area. Therefore SPeAR® is ideal for aiding progressive assessment at the early stages of decision making design. Also the illustrative diagram facilitates communication and discussion with stakeholders about the outcomes of the project.
Provides direction for improvement: SPeAR® assessment methodology identifies where there is room for improvement in an individual project and so provides directions to achieve optimum benefit.

a) Advantages
Involves a thinking process of a team not an individual: Because the indicators are distributed between diverse disciplines SPeAR® allows for the use of a diverse skills team to be involved in the assessments. One person can easily coordinate the assessment, but to assure the quality of the process, experts in different disciplines should be consulted in order to guarantee a more balanced and holistic assessment.

b) Disadvantages/Barriers
Oversimplification of the assessment system: The assessment is mostly qualitative rather that quantitative. This characteristic gives flexibility to the framework and an incentive to designers to think of alternative outcomes to enhance SD. However this flexibility is also responsible for creating an opportunity for the system to be misused by the subjectivity of the indicators.
Skillful team is required: SPeAR® requires a skillful team to ensure the quality of the assessment. This is because the quality of an assessment relies more on the skills and understanding of the assessment team rather than the software. Therefore in order to achieve a good assessment the team of assessors needs to be trained accordingly. This can represent an extra cost to some projects at the design stage if training is needed.
Master planning approach: Current SPeAR® indicators are designed for master planning assessment and therefore not always easily linked to geotechnical design.

b) Disadvantages/Barriers

Image of the brand: The SPeAR® brand is well associated with master planning assessment. In this way the name imposes a natural barrier for its use in geotechnical projects.

6.3.1: Implications for development of SPeAR® for geotechnical assessment

In understanding the possible advantages and disadvantages for using SPeAR® for geotechnical engineering assessment, the focus of the research was directed towards the development of improvements to the system. These improvements aimed to overcome the disadvantages (see Table 6.2) and adapt the framework to become more suitable for geotechnical assessment.

Because very little literature was available concerning the subject of sustainability assessment for geotechnical projects, the process of developing the strategy to overcome the disadvantages of the system was mainly based on information collected from attending conferences, talks and workshops regarding geotechnical engineering and or sustainability and also by interviewing professionals in the field of geotechnical engineering and sustainability assessment. This peer review combined with the literature review resulted in a list of adjustments considered necessary in order to make the most use of the advantages that SPeAR® offered whilst overcoming the disadvantages pointed out previously.

6.4: Key areas for improvements

The outcome of peer review and literature research was that three key areas of improvement were needed to enable SPeAR® framework to be adapted for geotechnical assessment.

6.4.1: Change of name

Peer review suggested that established tools such as BREEAM, LEED, CEEQUAL and SPeAR® already have their names linked with master planning and thus not associated with geotechnical engineering. Thus, to adapt SPeAR® a new name related to geotechnical engineering would be needed to immediately inform that the system was especially adapted with a focus on geotechnical projects.

6.4.2: Indicators

The SPeAR® assessment model is based on the performance of each indicator against a scale of best and worst cases and transferring the outcomes into a highly visual diagram that gives a unique visual profile of sustainability in the project (Braithwaite, 2007). As SPeAR® indicators were developed for master planning assessment most of the indicators are very broad. However careful analysis of the relevance of the indicators for the main areas of geotechnical engineering revealed that most indicators were applicable to geotechnical projects. Nevertheless, because the best and worse cases were not specifically designed for geotechnical use they normally clouded the vision of geotechnical designers from the potential of using theses broad indicators. In this manner the current arrangements of the indicators and best and worst cases created a barrier for a wider use of the SPeAR® tool for geotechnical assessment. Thus, to make the system more understandable for geotechnical engineers, some indicators and a great percentage of the best and worse cases needed to be revised and superseded for more geotechnically specific ones (see Section 6.5).

6.4.3: Embedding quantitative analysis

SPeAR® appraisal is based on the performance of each indicator against a scale of best and worst cases and each indicator scenario is aggregated into the relevant sector. The average performance of each sector is then transferred into the SPeAR® diagram (Arup, 2007). In this way the assessment relies on the qualitative analysis of the assessor. Thus a common criticism from engineers was that the system can be subjective, creating an opportunity for misuse of the tool. Therefore to improve SPeAR® transparency and narrow the interpretation of the results, quantitative analysis such Life Cycle Analysis (LCA) needs to be embedded into the system. Such analysis has the potential to put life cycle thinking into practice and improve supporting indicators through better numerical data. Moreover, LCA can also help engineers and clients to better understand the environmental trade-offs associated with alternative design options throughout their life cycle. Understanding that engineers expect to work with precise measurements rather than with qualitative analysis, quantitative analysis can benefit project decision-making in geotechnical engineering. Moreover as discussed in Chapter 3 and Chapter 4 the use of a single quantitative system for assessing sustainability can be highly misleading and fail to capture the essence of sustainability. Thus by combining a qualitative tool such as SPeAR® and a quantitative system such as LCA 'the best of both worlds' can be utilised in a complementary framework.

6.5: Modifying SPeAR®

By understanding the main obstacles associated with the use of the SPeAR® model for geotechnical assessment, a number of important modifications were made to adapt the tool for better geotechnical engineering use.

6.5.1: Name

To identify the new tool as a geotechnical system the name of the tool needed to be adapted. Therefore, for the purpose of this thesis and publications related to this research only, the adapted version of SPeAR® will be called 'GeoSPeAR'. This is in order to give the modified SPeAR® a geotechnically related name associated with the SPeAR® brand but clearly identifiable with geotechnical assessment.

6.5.2: Indicators

To improve the use of SPeAR® at the geotechnical level some modifications were made to the indicator system. First, the relevance of the indicators to geotechnical engineering projects was evaluated. In this manner, if these did not directly refer to geotechnical engineering decisions they were substituted for more suitable ones to make the ‘GeoSPeAR’ focused on geotechnical decisions. For example, under social responsibility, the indicator for donations to voluntary and community organizations was excluded given that this is an important indicator for companies and master planning of projects but it is not a decision directly linked to geotechnical choices in isolation. In a similar manner, after detailed analyses, 11 indicators were excluded form the systems given that they were not easily linked to geotechnical decisions (see Table 6.3).

Table 6.3: Indicators Excluded

6.3: Indicators excluded			
	Section	**Original indicator**	**Explanation**
1	Social responsibility	Donations to Voluntary & Community Organizations	This indicator is to measure contribution to community. Although this is an important indicator for companies and projects, most of the time, these are not decisions directly linked to geotechnical choices.
2	Access	Key Facilities	This indicator is to measure how accessible a project is to shops, banks and other key facilities. This indicator is very relevant for building projects; however it is not normally a key indicator for geotechnical projects.
3	Access	Education & Lifelong Learning	This indicator is to measure how accessible the building is to local schools, providing good access to education for users. Again, this is a key indicator for residential buildings but not for geotechnical projects.

4	Access	Housing Types	This indicator measures housing types, including affordable housing. This is to assure a good range of housing types is included in master planning. This is a key indicator for residential development projects but not for geotechnical projects.
5	Access	Telecommunications	This indicator measures appropriate provision of effective communication and internet access to projects. Again, this is a key indicator to building projects but not very relevant to geotechnical projects.
6	Form & Space	Public & Private Realm	This indicator is to measure the quality of appropriate public operational and private recreational spaces. Again, this is a key indicator for building projects and developments but not for geotechnical projects.

7	Stakeholder Satisfaction	User Controls	This indicator measures provision of individual user controls, with guidance, for each aspect of indoor environment. A key indicator to building projects but not to geotechnical projects.
8	Health & Wellbeing	Provision of Support Facilities	This indicator measures the provision of crèche facilities and other support facilities for projects. This will be relevant to geotechnical projects just during construction. In this case this will be measured by the ‘condition of work’ indicator.
9	Water Discharge	Sewage Treatment	This indicator measures utilization of on site organic process treatment facilities. Again this is a key indicator to building projects but not very relevant to geotechnical projects. Indicators on the water discharge section such as ‘drainage systems’ and ‘risk management of water pollution’ will assess water discharge during construction and operation of geotechnical projects.
10	Transport	Public Transport Infrastructure	This indicator measures the proximity of the project to public transport during operation, in order to facilitate users to reduce carbon emissions. A key indicator to building projects but not necessarily to geotechnical projects. During construction, this will be measured by ‘choice of transport’.

11	Transport	Pedestrian/ Bicycle Facilities	This indicator measures provision of facilities and incentives for cyclists during operation, in order to facilitate users to reduce carbon emissions. A key indicator to building projects but not to geotechnical projects. During construction, this will be measured by ‘choice of transport’ as well.

Similarly, after detailed analyses 8 indicators were created/substituted to improve the system in aiding geotechnical choices (see Table 6.4). In total only 8 indicators were added/substituted given that the original SPeAR® framework is holistic and current, and therefore does not need much adding to it. As an example, under the social responsibility section, two indicators were created to improve questioning about sustainable resourcing for materials given that geotechnical works can be responsible for large consumption and movements of construction materials. Moreover, geotechnical designers need to be made aware of the consequences of their choices of material and opportunities hidden on those decisions. Thus, ‘fair trade resourcing’ and ‘responsible resourcing’ indicators were created. ‘Social fair trade’ deals with the labour conditions of suppliers, especially for suppliers coming from outside of the UK and ‘responsible resourcing’ questions designers about the future implications and sustainability of the material sources.

Table 6.4

6.4 Indicators created/ substituted							
	Section	**Original indicator**	**Modification**	**New indicator**	**Modified best case**	**Modified worst case**	**Focus on**
1	Social responsibility		Created	Fair trade	Consideration given to trading conditions of materials	No consideration is given to trading conditions of materials	This indicator was created to assess consideration of fair trade of materials during specification of materials.

2	Social responsibility		Created	Responsible resourcing	Consideration given to ensure the sustainability of the source of materials	Consideration not given to future implications of the materials trading for the source	Indicator created to measure the consideration of the sustainability of the source of material when specifying and procuring materials. This is to ensure designers consider where materials come and the implications of material choice to future supply availability.
3	Social responsibility	Global Supply Chain	Substituted	Ethical international trade	Use of international ethical codes for resourcing of materials	No use of international ethical codes for resourcing of materials	This indicator was created to measure the consideration of the global ethics when sourcing of materials. This is to ensure designers consider where materials come and the global moral implications of material choice.

4	Social responsibility		Created	Environmental friendly resourcing	Consideration given to the effects to environment during trade of materials	Consideration not given to effects of the trade to the environment	Created to measure the consideration of the environmental effects when specifying and procuring materials. This is to ensure designers consider environmental aspects of material choices.
5	Competition Effects		Created	Marketing Effects	Consideration given to the marketing advantages of sustainability	Consideration not given to the advantages of sustainability as a marketing tool	Created to measure the consideration of sustainability as a beneficial factor in marketing the project. This is because the embedment of sustainability into a geotechnical project will promote a balance of economic, environmental and social aspects and also ‘future proof’ the project enhancing competition effects. This needs to be considered to account for the positive economic benefits of embedding sustainability into a project.

6	Stakeholder Satisfaction	Customer Satisfaction	Substituted	Client satisfaction	Consideration given to the interaction between geotechnical designer and the other links in the project chain. Give consideration to feedback system. High level of client satisfaction	Consideration not given to feedback system	This indicator was created to measure the consideration given to client's satisfaction and to support better communication and interaction between geotechnical engineers, clients, architects and contractors during the design process.

7	Viability	Service Contracts	Substituted	Adequate site investigation	Strategic site investigation. Consideration given to security and efficiency of the design when planning site investigation	Minimum site investigation. No consideration of the efficiency of the design when planning site investigation	This indicator was created to measure the consideration given to strategic site investigation. This is because appropriate site investigation can support not just safety but also efficiency of geotechnical design because better understanding of the soil will support less conservative design.
8	Viability	Operations Management Tools & Technologies	Substituted	Efficiency of design	Consideration given to the most efficient sustainable design option possible and to life cycle	Conservative design. Consideration not given to the life cycle of the structure	This indicator was created to measure economic efficiency of design. This is to ensure the viability of the project is considered when improving efficiency in different areas such as ‘water efficiency’ and ‘energy efficiency’.

					analyses if necessary		

When indicators were suitable but the best and worse cases were not linked to geotechnical design some modifications were also necessary. For example, under the natural resource section, the indicators for daylight originally had the best and worse case focused on buildings. Best case would be appropriate use of daylight, with natural lighting used during daylight hours and worse case would be artificial lighting used throughout and at all times. As most of the geotechnical structures will not be related to these best and worst cases after completion, the indicator was kept but the focus was changed to allow consideration throughout the life of the project including construction. Thus the best case became, appropriate use of daylight or renewable resources of lighting during construction (including underground and nighttime construction), operation and maintenance, and worse case became, artificial lighting used throughout and at all times during construction, operation and maintenance. In this new arrangement this indicator would make geotechnical engineers aware of the energy demands of their projects and would also encourage planning ahead to allow the use of renewable sources of energy given any need for artificial lighting throughout the geotechnical projects. In total 8 best and worse cases where adjusted (see Table 6.5).

Table 6.5

6.5: Best and worst cases changed							
	Section	**Original indicator**	**Modification**	**Current best and worst cases**	**Modified best case**	**Modified worst case**	**Focus on**
1	Form & Space	Internal & External Security	Change best and worse case	Best: Low level of crime and fear of crime. Worst: Increases level of crime and fear of crime.	Consideration given to security of the site and of the community during construction	Consideration not given to security of the site and of the community during construction	Change focus of the indicator from occupation to construction.

2	Form & Space	Communal / Circulation Areas	Change best and worse case	Best: High quality circulation areas, recreation facilities and catering facilities. Worst: Substandard / poor quality communal and circulation facilities.	Consideration given to high quality facilities during construction.	No consideration given to high quality facilities during construction.	Change focus of the indicator from occupation to construction.

3	Form & Space	Right of Lights	Change best and worse case	Best: Consideration given to rights of light (s) both within the site and for neighbours, improving existing conditions. Worst: significant loss of light to surrounding buildings.	Consideration given for the workers' right of light during construction. Organize schedule of work given consideration to natural lighting. Concerning is given to the use of renewable source of energy if additional lighting is needed	Consideration not given to the right of lights and the sources of artificial lighting during construction	Change focus of the indicator from occupation to construction.

4	Stakeholder Satisfaction	Indoor Air Quality	Change best and worse case	Best: Design, systems and maintenance in place to ensure ideal indoor air quality. Worst: No consideration given air door quality.	Consideration given to the air quality during construction and maintenance.	No consideration given to air quality during construction and maintenance.	Change focus of the indicator from occupation to construction and maintenance.
5	Stakeholder Satisfaction	Occupants' Satisfaction	Change best and worse case	Best: full consideration during design and operation of comfort issues. Worse: no consideration given to comfort issues.	Full consideration is given to the maintenance process.	No consideration is given to the maintenance of the project.	Change focus of the indicator from operation to maintenance.

6	Transport	Choice of Transport	Change best and worse case	Best: Achieves more sustainable transport choices –alternatives to travel by single-occupancy private car. Worst: Totally dependent on the private car for travel.	Consideration given to transport of people and materials to site during construction and maintenance.	Consideration not given to transport of people and materials during construction and maintenance.	Focus on site operations and maintenance.
7	Water Use	Auxiliary Water Source	Change best and worse case	Best: Auxiliary water. E.g. for watering lawns is supplied from on-site renewable sources. Worst: No consideration of auxiliary water.	Consideration given to the choice of water source during maintenance.	Consideration not given to the choice of water source during maintenance.	Focus on maintenance.

8	Energy	Daylighting	Change best and worse case	Best: appropriate use of daylighting, with natural lighting used during daylight hours. Worst: Artificial lighting used throughout and at all times.	Appropriate use of daylight during construction. Maximize natural lighting.	Artificial lighting used during all times during construction	Change focus of the indicator from operation to construction.

6.5.3: Embedding quantitative analyses

Finally, in order to improve transparency of some indicators, numerical analysis was found to be important to complement the colour scale currently in use and overcome some of the earlier critics of the SPeAR® approach. This would involve the identification of the key indicators for each project and numerical analyses for these particular indicators to be embedded into the 'GeoSPeAR' assessment model. In this manner, sections such as air quality, water use and energy could be supported by Life Cycle Analysis allows the inclusion of calculations of CO_2 and other emissions, water consumption and embodied energy of materials. These key indicators would need to be agreed with clients and designers before the beginning of the assessment.

It is important to note that the use of numerical analyses needs to be restricted to very important indicators given that collating the data and analysing them can be a very time consuming and costly process, even with the help of advanced software such as Gabi 4 and SimaPro (Menzies *et al*., 2007). Moreover, to generate adequate numerical data to assess a future design option, the creations of future scenarios are required. This assumes future results, which are often very difficult to predict given that some outcomes are sometimes completely unexpected (Jefferson *et al*., 2010). Nevertheless, numerical analysis allows examination of the possible outcomes of projects from "cradle to grave" and provides better understanding of how each decision is interconnected to the future outcome of the whole project. Thus, the use of numerical analysis allows 'GeoSPeAR' to embed the advantages of a combined analytical and qualitative sustainability assessment approach advocated by Elgahli *et al*., 2008.

An example of this combined approach is the calculation of the carbon footprint of different design options and the embedment of the results into the ‘direct emissions’ and ‘associated or indirect emissions’ indicators in the air quality section under the environmental set of indicators in ‘GeoSPeAR’. As mentioned previously (see Chapter 3) carbon calculation for geotechnical engineering has been the theme of previous research projects, and some even use carbon measurement as an indicator for the sustainability of the projects (Jefferson *et al.*, 2010). Moreover as the ICE stated the challenge for the engineer in the low carbon age is to understand and minimise carbon emissions associated with designing, constructing, and operating projects while meeting society’s needs (ICE, 2009).

In this manner the carbon footprint can become a key indicator for specific projects and the life cycle balance of a specific material, transport process or design option could be analysed and embedded into ‘GeoSPeAR’ (an example of this approach will be presented on Chapter 8). In a similar way, other indicators such as water and energy consumption, employment and recycling content can be supported by numerical calculation and embedded into the ‘GeoSPeAR’ framework. This numerical support can more precisely aid geotechnical engineers to understand the underlying issues of a project and the outcomes of each decision made through the geotechnical design process.

With these three main adjustments, the ‘GeoSPeAR’ system will be used as part of a robust framework to support the assessment of sustainability at the geotechnical level. This is to enable designers to cover social, environmental and economic aspects of geotechnical projects understanding the true extent of the impact of geotechnical works. The detailed methodology will be presented in Chapter 7.

CHAPTER 7: Embedding Sustainability Into Geotechnical Projects Through the 'GeoSPeAR' Framework

The overall objective of using a framework for geotechnical assessment of sustainability is to enable designers to cover several aspects of sustainability during the design decision-making process and delivery of more sustainable projects. Thus, the 'GeoSPeAR' methodology developed in this research intends to support geotechnical engineers during the decision making stages to achieve this objective.

7.1: Intermediate targets to be achieved

Understanding that the embedment of sustainability into geotechnical projects is a significant task and can appear to be intimidating and discouraging for geotechnical engineers, the 'GeoSPeAR' framework defines five intermediate targets to be achieved during the 'GeoSPeAR' process (see Figure 7.1).

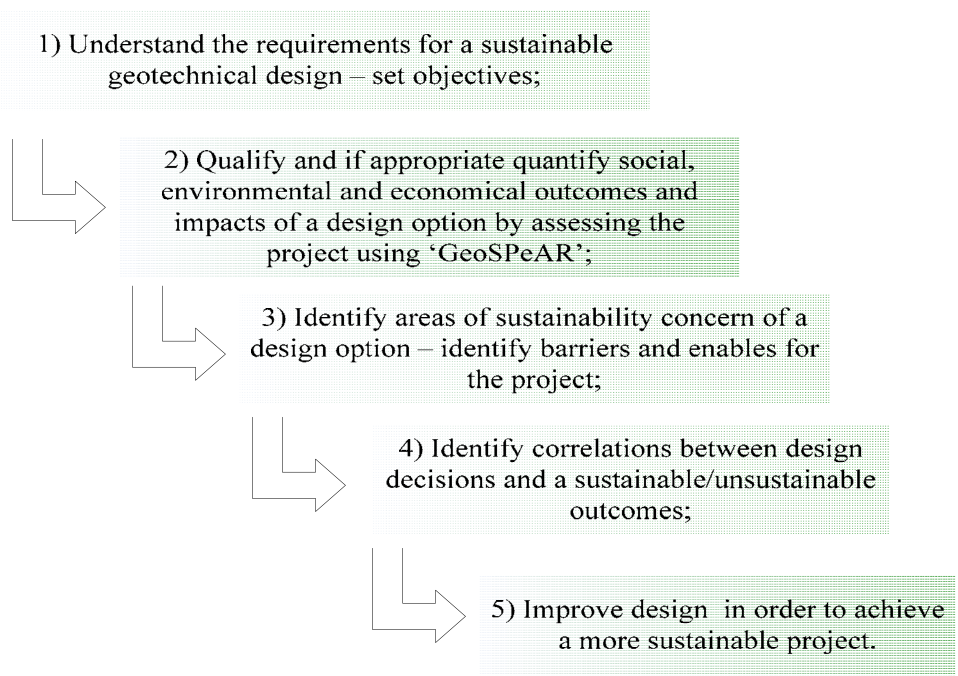


Figure 7.1: Intermediate targets to be achieved by using the 'GeoSPeAR' framework

These five intermediate objectives are aimed to take the designers through a process of logical reasoning that drive embedment of sustainable development ideals and the identification of opportunities and barriers to improvements.

To fulfill these targets, an assessment framework is needed that can be used for geotechnical projects, embedding the revisions described previously in Chapter 6 Section 6.5. Thus this research developed a seven step framework to achieve there targets. This framework aims to guide engineers through the design process, exposing the impacts of each decision and giving information and direction in order to achieve a more sustainable project outcome. This framework guides the geotechnical engineer on a step by step basis throughout the 'GeoSPeAR' assessment process. Each step of the framework defines necessary actions, which need to be taken into account in order to achieve identified opportunities (see Figure 7.2).

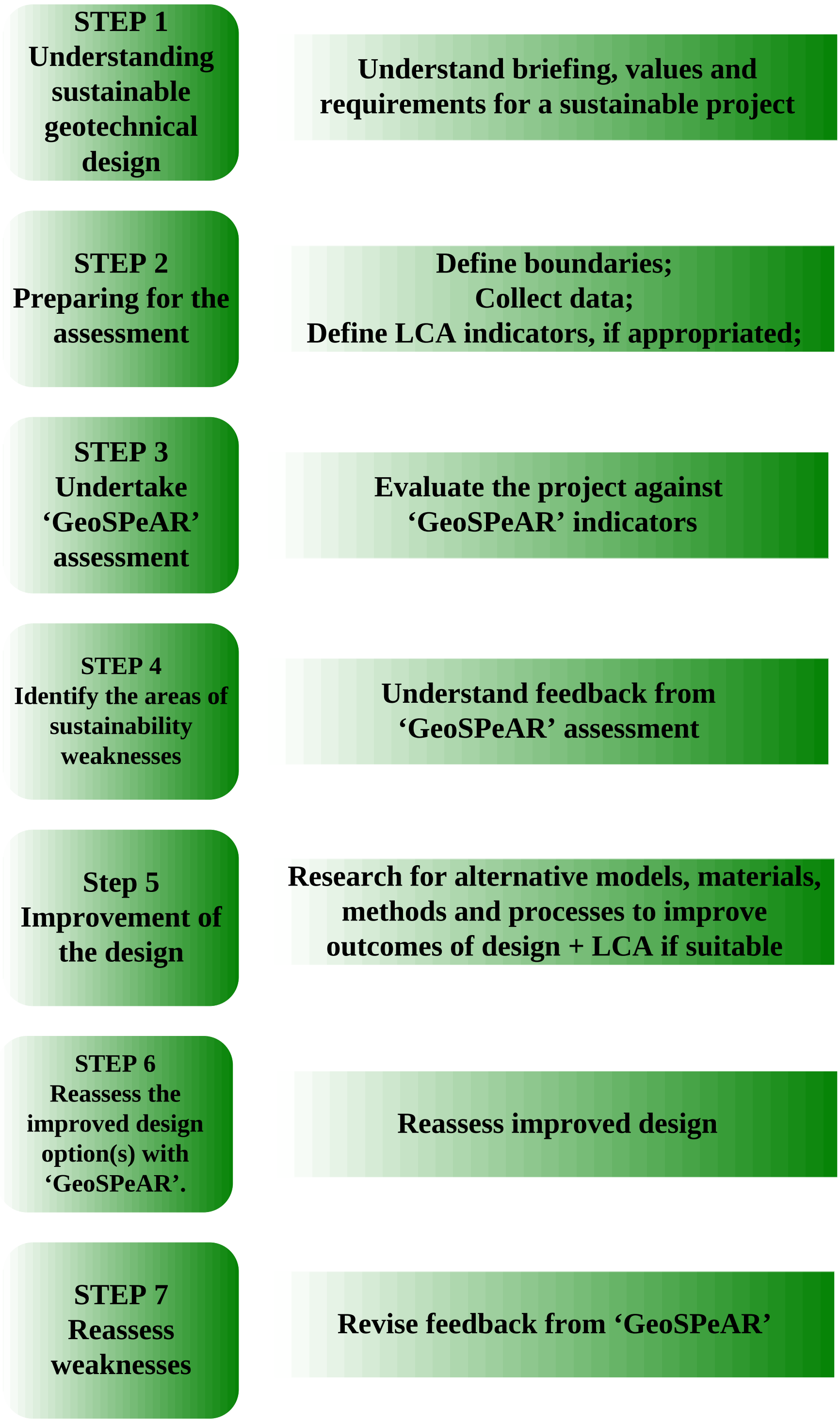


Figure 7.2: Seven step methodology for embedding sustainability into geotechnical design.

7.2: Seven steps methodology

7.2.1: STEP 1 – Understanding the project

Step 1 – Communication between all parties involved in the project is essential. Before starting the assessment it is important to interact with clients, suppliers, contractors and other engineers in order to ensure they are aware of the assessment and open to discuss possible adjustments when weakness are spotted. This communication and interaction is not always possible but effort should be spent in improving it to guarantee the strength of the framework.

In any engineering project the first step of the design process is to understand aims, values and requirements of the project. This is imperative in order to guide the decision making process and ensure requirements are met.

Currently in the UK, designers and planners are being required by government to address sustainability and embed sustainability values into their projects into all stages (Strategic Forum for Construction, 2008). The sustainability agenda for geotechnical design is very broad with overarching complex issues such as energy efficiency, resources management, pollution controls, social and economical decisions. Current literature however do not provide sufficient guidance about when specific sustainability issues should be addressed (see Chapter 3), who actually makes decisions and what influences them, or how different stakeholders are engaged (Boyko *et al.*, 2006).

Thus, if sustainability is to be embedded effectively into geotechnical design from early stages, it is important to communicate the sustainability values expected from the project at the beginning of the decision making process, during the briefing stage. As an example some of the main targets established at the beginning of the project could be to improve energy efficiency, reduce carbon footprint and to resource materials as locally as possible.

By using 'GeoSPeAR' as part of the briefing process, a set of clear overarching indicators can be used by designers. These indicators, together with a range of expected outcomes (best and worst cases), will guide the geotechnical engineers in understanding what needs to be addressed in order to achieve improved sustainability.

In many cases, price and programme may still be the priorities at the briefing stage, but by promoting sustainable values from early stages of design, engineers have the opportunity to review methods and embed sustainability in the overall project. Moreover if sustainability is very highly regarded on the project this will allow geotechnical engineers to explore the use of sustainable materials and innovative solutions with a viable price and time constrains considered.

This first step may sound almost self-evident and easy to follow, but if not stressed can easily undermine the need of successful enhancement of sustainability values achieved during a project. In this case communication throughout the design chain can become disjointed causing loss of resource flow and breaking down of the essential joined up approach needed to achieve sustainability (Taskforce on Sustainable Construction, 2007). This normally happens because engineers generally divide work into tightly defined jobs and narrowly organised work unities, with communication or joint consultation across these unities being uncommon. This tendency to compartmentalise work and knowledge has the potential to become an obstacle for sustainable outcomes by restricting broarder perspectives and integrated solutions required to embed sustainabilty into geotechnical projects (Fenner and Ryce, 2007).

In this way, the best way to complete this first step is to provide a clear, comprehensive brief introducing 'GeoSPeAR' as a tool for assessment of design options. This will help to communicate sustainable values from masterplanning to the geotechnical designers, guaranteeing a joined up approach, thus enabling important issues identified as barriers to sustainability to be tackled and supporting the enhancement of the design in order to achieve more sustainable outcomes.

7.2.2: STEP 2 – Preparing for the assessment

Step 2 – Set up boundaries for the assessment. The flexibility of the framework means that a number of boundary conditions can be accommodated. For example, geographic boundary could be the site and surrounding areas (in, say, a 5km radius); supply chain issues could be restricted to the first and significant second suppliers (Braithwaite, 2007). It is valuable to clearly understand the boundaries before starting the assessment in order to optimise collection of data. Understanding the boundaries the collection of data can be carried out. Depending on the stage of the project, the data can be outline ideas for possible design options or real information from the site, contractors, materials, etc. The quality of the data is the main factor in guaranteeing success of the assessment; thus, the assessment will be as good and objective as data allow.

(I) Defining Boundaries

A project normally has several boundaries. These can be defined by the geographical position of the site/sites, the community and stakeholders affected/benefited by the project and the supply chain involved with the project. When embedding sustainability and assessing the outcomes of a project, boundaries are important to define how far these outcomes are expected to be improved. Therefore, boundaries will define the social, environmental and economic aspects to be accounted for in the assessment. Once the full extent of impacts/effects are analysed, the broad and complex interchange between the three pillars can be understood.

When using ‘GeoSPeAR’, the flexibility of the framework means that a number of boundary conditions can be accommodated. Therefore, before starting the data collection for the ‘GeoSPeAR’ assessment it is important to define essential boundaries:

(a) Geographical boundaries: Geographical boundaries are necessary for indicators such as contaminated land, energy monitoring and similar indicators that are defined within site and its surroundings.

(b) Stakeholder’s boundaries: Stakeholder’s boundaries are necessary for indicators such as external reporting, social identity and similar indicators which relate to stakeholder engagement/ involvement.

(c) Supply chain boundaries: Supply chain boundaries are necessary for indicators such as ethical sourcing, environmental sourcing and similar indicators, which need to be assessed within the supply chain.

These main boundaries will be sufficient to define the extent in which all the current indicators within the ‘GeoSPeAR’ system will be assessd. However, if a specific boundary is necessary for an additional indicator, the team needs to discuss and agree this boundary before collecting data for the assessment.

(II) Collecting Data

Before beginning the ‘GeoSPeAR’ assessment the geotechnical engineers need to collect data for every indicator. The information collected is crucial to the quality of the assessment. This is because the results shown on the ‘GeoSPeAR’ diagram are a direct reflection of the data used to complete the worksheets. However the degree to which data will be collected will depend on the availability of the data and the quality of the data available.

Data are not always available at the beginning of design stage. There are often times when geotechnical design starts or even finishes before environmental surveys have been completed and other further investigation into processes and materials have been understood. This should be avoided in order to refrain for making uninformed choices.

Data gathering at the early stages of design is crucial for informed decision making. By assessing the design with ‘GeoSPeAR’ engineers need to gather data before making decisions. This will motivate questions to be asked and further investigation to be conducted in order to collect the necessary data for the assessment.

However, if some data are still not available for the assessment, this should not stop the process. A lower score should be achieved where no information is available. This is to highlight the potential risks for sustainability and the impact across the project, due to the lack of essential data for the assessment. In this manner engineers can recognise where there is lack of data at the beginning of project but also move the assessment forward even with missing data.

It is important to notice that the quality of the data collected is very important for the assessment. This is because the final evaluation of the sustainability of the project will come from the analysis of the data against the ‘GeoSPeAR’ indicators. In this manner, the result of the assessment is limited by its data.

(III) Life Cycle Analyses (LCA)

If sufficient data are available and are of sufficient quality to inform the decision-making process, LCA can be used as a complementary tool. LCA seeks to quantify significant aspects and impacts over the whole life cycle of a process or a product (Hyde *et al.,* 2006). Thus, by combining LCA with the 'GeoSPeAR' assessment system quantitative data can be used to complement the qualitative analyses of some of the indicators allowing objective numerical assessment to be used.

The level of complexity depends mainly on the reason for undertaking the assessment. LCA can be general (e.g. key inputs and outputs across the main stages), they can focus on one key issue (e.g. the global warming potential of the system), or they can be detailed and comprehensive (detailing inputs and outputs through a thorough breakdown and analysis of each stage) (Hyde *et al.,* 2006).

To use LCA in supporting 'GeoSPeAR' methodology key indicators need to be identified early in the design process. These key indicators will be the ones that better assess the key outcomes that are important for the success of the project, according to client expectations. Examples could be carbon, air quality, and water consumption.

Once key indicators are identified and agreed, data need to be collected for the LCA assessment. With data available, the LCA will be carried out and the results embedded into the 'GeoSPeAR' assessment to provide quantitative data for the indicators chosen.

However, detailed LCA can require significant resources and expertise. Therefore key to the successful combined use of 'GeoSPeAR' and LCA is flexibility. Flexibility is important to free designers and clients to use LCA as much as possible and also be used when relevant and quality data are available.

7.2.3 STEP 3 - Undertake 'GeoSPeAR' assessment

STEP 3 – Undertake the baseline assessment that will result in the initial baseline diagram; this diagram then provides guidance on the potential for improvement.

With data available, the 'GeoSPeAR' assessment can be undertaken. The SPeAR® model suggests that the assessment follow 6 main stages. This approach has been kept in 'GeoSPeAR' as it has robust and well used assessment stages. The six main stages are:

1) Understanding the Issues – A meeting with the client at this stage is important to obtain a comprehensive understanding of the project.

2) Identify Stakeholders – During this stage all relevant stakeholders, internally and externally, are identified to facilitate the assessment of the impacts on stakeholders.

3) Indicator Review - SPeAR® has a core set of indicators, which reflect global indicators and these are generally applicable to most SPeAR® appraisals. Project and sector specific indicators may need to be inserted where appropriate before an assessment is carried out. Project specific indicators might include car-parking facilities, developed in accordance with relevant planning guidance (Arup, 2007). Hence, 'GeoSPeAR' utilises the same approach.

4) Data Collation - This can take the form of reviews of documentation, meetings with business sector leaders/managers, site walkovers and discussions with stakeholders. For 'GeoSPeAR' this will be undertaken and needs to be completed before the appraisal stage.

5) Workshops - Workshops can be with key project contacts or can include external stakeholders. The purpose of the workshop is to go through the indicators and receive information and views from the attendees, but not to carry out the actual assessment (Arup, 2007).

6) Undertake Appraisal – The assessment performance of each indicator against a scale of best and worst cases and each indicator scenario is aggregated into the relevant sector. In order to display both negative and positive results, a median line designates good practice (cream colour, see Figure 7.3). Positive results (green tones) are represented from the median line towards the centre of the diagram. Negative results (red tones) are represented from the median line towards the circumference. The average performance of each sector is then transferred into the 'GeoSPeAR' diagram. The spreadsheet behind the production of 'GeoSPeAR' diagram, where all the data are entered and analysed, ensures that the assessment is fully tractable and can be revised or improved at any time throughout any given project (Arup, 2007).

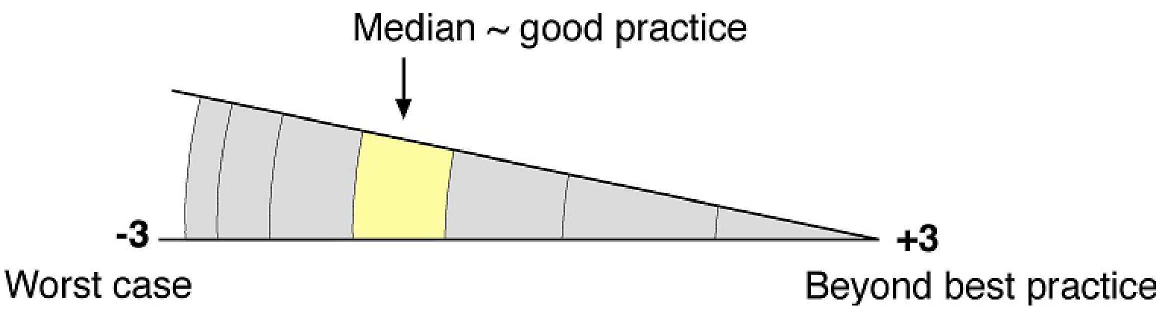


Figure 7.3: SPeAR® scoring scale

The assessment can be undertaken as precisely intended by the assessor, according to the availability and quality of data, and the assessor's experience. However, independently of the experience and background of the assessor, the 'GeoSPeAR' framework provides guidance and benchmarking for any assessor by providing a structured methodology, relevant indicators and updated best and worse cases to support the assessment.

By evaluating the project against all the ‘GeoSPeAR’ indicators engineers can obtain a view of best practice in sustainability and how close or far their projects are from the ‘GeoSPeAR’ sustainability benchmarking. Thus ‘GeoSPeAR’ can assist in setting sustainability objectives, tracking the sustainability of a project through its life and assessing alternatives where a decision is to be supported.

The results from the assessment process will provide a colorful diagram with the overall view of the sustainability of the project.

7.2.4: STEP 4 - Identify the areas of sustainability weaknesses

STEP 4 – Identify the areas of sustainability concerns and where there is need to explore different design options. Identify where there is opportunity for improvement towards sustainability.

The assessment will result in a colorful diagram with the results of the data analyses. This diagram illustrates the performance of groups of indicators by shading in a segment on the face. The closer that segment is to the centre of the diagram the stronger it is in terms of sustainability: conversely the further away it is from the centre, the weaker this becomes (see Figure 7.4).

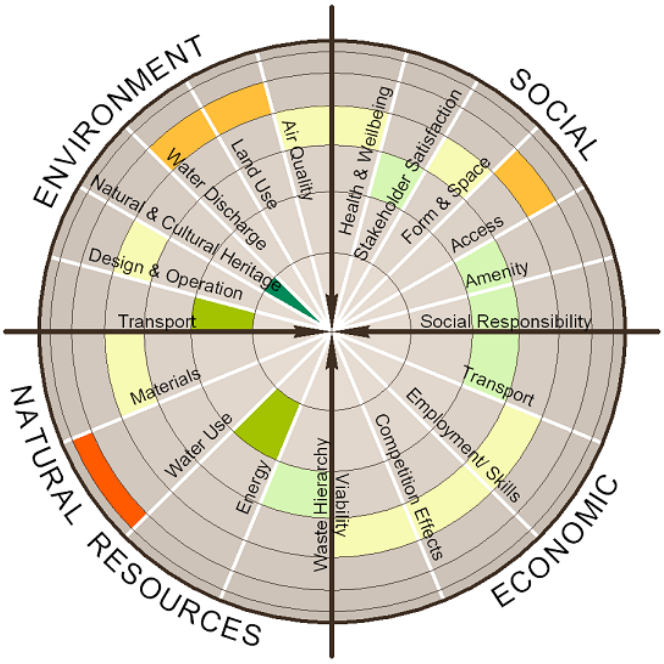


Figure 7.4: 'GeoSPeAR' diagram (Arup, 2007)

A 'GeoSPeAR' diagram, like the SPeAR® diagram, can be compared to a dartboard with the aim being to have as many segments as possible close to the centre (Braithwaite, 2007).

This diagram (Figure 7.4) is one of the main advantages of using 'GeoSPeAR' rather than other checklist systems. With this diagram in hand designers can visually understand the concerns of the design option and the correlation between different outcomes. Moreover designers are challenged to evaluate alternative options, improvements and opportunities for embedding sustainability into the project in order to improve the areas highlighted as weakness. This is then undertaken during Step 5.

7.2.5: STEP 5 – Improvement of the design

STEP 5 – Re-evaluate the design and consider changes needed to improve sustainability. This allows geotechnical engineers to improve the design guided by sustainability priorities.

Understanding the outcomes of the project, strengths and weaknesses of the design allows engineers to improve their ideas and methods, and move towards a more sustainable outcome.

At this stage of the framework engineers have the opportunity to receive feedback and comprehend their options and choices for further improvement. By understanding the weaknesses of their solutions, they can look for alternative models, materials, methods and processes to reduce the non-desirable effects of projects and also improve the desirable outcomes.

This feedback step within the framework provides an opportunity to re-evaluate design allowing engineers to challenge the status quo of many available geotechnical solutions. With this opportunity to rethink design, considering the sustainability of outcomes, engineers have a real chance to embed sustainable values into geotechnical projects and achieve their full potential in improving the sustainability by simultaneously considering, social, environmental and economic aspects of their designs.

Moreover as engineers work to improve the weakness highlighted in the 'GeoSPeAR' diagram they will realise that there is no such a thing as off-the-shelf sustainable solution that will work in all cases. Instead, there will understand the range of engineering solutions that can improve the sustainability of a specific project.

7.2.6: STEP 6 - Reassess the improved design option(s) with 'GeoSPeAR'

STEP 6 **–** Carry out a reassessment to include any improvements made to design option(s).

After improving design, a new assessment must be undertaken to guarantee that the new improvements are not creating other weakness on the overall design. In this manner a final review of data and scoring must be carried out and a final evaluation of the 'GeoSPeAR' diagram must be undertaken.

7.2.7: STEP 7 - Reassess weaknesses

SETP 7 – Reassess any areas of concern raised during the reassessment and repeat Step 5 and 6 as often as necessary according to the level of improvement expected for the project.

After reassessing the project, the revised diagram will also present areas for improvement, as no design is perfect and no project is completely sustainable. However, at this stage of the framework, where designers should already understand the trade-offs between outcomes, and the opportunities to improve their project, a decision can be made to evolve a design option. This decision can be reached by comparing alternative 'GeoSPeAR' diagrams and making a decision regarding the overall impact of the project. Thus, alternative scenarios can be evaluated and the complex interplays across the three pillars assessed objectively.

However, if the improved design and final diagram still need overall improvement, Steps 5 and 6 need to be repeated as required. This process can be repeated as many times as necessary until satisfactory improvement can be achieved.

7.3: Achieving the objectives of the framework

Through the 'GeoSPeAR' diagram important issues can be raised; however, the definitive answers are not provided by the system but by the geotechnical engineer who should be willing to improve design towards sustainable development. Nevertheless 'GeoSPeAR' promotes discussion from which more sustainable solutions can be derived and therefore support the designer in embedding sustainability into geotechnical projects.

In this manner it is imperative to assess opportunities for sustainability improvement during the design process if sustainability is to be embedded into projects. This is because frameworks which assess geotechnical projects after the completion of the design have little or no opportunity to influence improvements. In the same way sustainability revisions carried out after the completion of the geotechnical design have small chance to improve the overall sustainability of the project. Thus 'GeoSPeAR' provides a targeted approach to be used during design to assess key areas of weakness in a project's sustainability.

By achieving the objectives of each step of the framework, geotechnical engineers should also be able to achieve the main objective of embedding sustainability into their decision making process to design more sustainable geotechnical projects.

It is important to note that a project is not expected to achieve all of the most optimum sectors towards the centre of the diagram: the ultimate achievement of a project is to have as many sectors in this area as possible (Braithwaite, 2007).

By focusing on the exploration of what might be achieved, building on the collective experience and ideas of the whole team and avoiding premature focus on apparent problems by fragments, a team of geotechnical engineers can discover sustainability opportunities, which rarely become visible under more traditional approaches (Price *et al*, 2009).

In this manner, the framework will help designers to capture opportunities to enhance sustainability and to define the actions required for their delivery. This is because this framework integrates sustainability assessment within the geotechnical design process, enabling geotechnical engineers to cover overarching aspects of sustainability during the decision-making stages. Also the framework shows that sustainability assessment can become a part of the design process rather that an exercise to be performed after decisions have been made. As a result geotechnical engineers can understand their potential in improving the sustainability of their projects and their opportunities to innovate and change the current outcomes of geotechnical projects.

The next chapter (Chapter 8) will demonstrate the use of the framework through three case studies. These will also be to demonstrate how different aspects of ‘GeoSPeAR’ can be used to help improve sustainability in geotechnical engineering.

CHAPTER 8: Case Studies

In order to illustrate the 'GeoSPeAR' approach three case studies have been assessed using the methodology described in Chapter 7. This is to demonstrate how the assessment system works in terms of its practical application and how it can support designers in highlighting strengths and weaknesses of design, understanding, improving and embedding sustainability into geotechnical projects.

8.1: Dartford Creek

The first case study aims to illustrate how the application of sustainability can help geotechnical engineers to evaluate better design choices and improve the level of sustainability for the overall project, during the design process.

To demonstrate this, an embankment project was analysed and assessed using 'GeoSPeAR' considering three different scenarios. The objective of comparing three scenarios was to demonstrate how the embedment of sustainability values would make a difference to this project if different approaches were taken during the early stages of design.

The three scenarios/approaches chosen to be evaluated in this first case study were:

(1) A traditional approach, i.e. a cost driven, low risk geotechnical design approach with no real consideration of either environmental or sustainable issues;

(2) An innovative environmental approach, i.e. targeted environmental assessments incorporating a combination of 'hard' and 'soft' engineering approaches; and

(3) A fully holistic sustainable approach, i.e. chosen to highlight the benefits that can be gained with appropriate foresight.

Assessment of the first and third scenarios was carried out by considering hypothetical data based on discussion with consultants and by taking the extreme view in each case. The second scenario refers to the actual design adopted and is based on real information from the case study site.

Because two scenarios are hypothetical, it should be noted that some of the design decisions assessed are dependent on assumptions. However, this should not be seen as a limitation to the assessments because the objective of this exercise is to illustrate how 'GeoSPeAR' can help and influence designers to rethink their decisions and improve sustainability before the development of the detailed solution. For the same reason, this case study goes only as far as the assessment of preliminary design, with some discussion of possible detailed design.

8.1.1: Overview of the project

The project site was located on the River Darent, a tributary to the River Thames, in East London. It consisted of two stretches of embankment along the River Darent close to its confluence with the River Thames approximately 20km East of Central London.

Dartford Creek is one of the last remaining natural tidal creeks in London. The flood embankment along Dartford Creek has significant social value because it provides 1:1000 year flood protection to 620 residential and commercial properties. This embankment was part of an existing flood defence system constructed in the 19^{th} century and due to the poor state of the current structure in place, it needed remedial measures to prolong the useful life of the flood defence. The flood embankments had suffered multiple failures in recent years, urgently requiring a permanent solution.

A £5 million Grant-in-Aid scheme, designed by Arup and constructed by Team Van Oord for the Environmental Agency, returned the channel to its historical position and provided long-term erosion protection to the flood embankments. The Environment Agency specifically required from the designers, at the beginning of the design stage, an innovative geotechnical solution in order to achieve a more environmentally focused design.

To meet these requirements the solution adopted was a combination of geotechnical and environmental engineering. To maintain the integrity of the flood embankments, a combination of steel sheet piling and timber brushwood faggots was installed to stop the erosion of the embankments on the outside of the river bends.

The sheet pile wall was installed to provide backup to this soft engineering system. Layers of brushwood faggots were placed on the existing slopes to provide the long-term slope profile. The brushwood faggots were placed in front of the piling, being laid between, and supported by, brushwood stakes. The design was based upon silt being deposited between the spaces in the brushwood, which is then trapped and cannot return to the water. Over a period of time the brushwood faggots should become completely buried both aiding embankment stabilisation and enhancing the salt marsh, a recognised Biodiversity Action Plan habitat.

Rock rolls, a type of gabion basket with a circular section, were used to protect the toe of the re-profiled slope against channel erosion. A long-term monitoring programme of the development of the slopes was required to be in place after completion. This uses the latest in terrestrial LiDAR remote sensing technology, to help assess the impact of the repair programme on the geomorphology of the area.

8.1.2: Design summary

When the client commissioned the design for the remediation of the flood protection, they provided a limited amount of desk study and previous ground investigation information. This information was reviewed and interpreted by the designers. No additional ground investigation was provided during the detailed design stage, nor was any information available on the groundwater conditions in the alluvium, which is critical for the analysis of the stability of the slopes and the design of the retaining wall.

Given the limited available data and the very novel approach to designing remedial works for flood defence in soft alluvium, without the backup of previous case histories for the ground conditions, reasonably conservative assumptions were made for the design.

In addition, due to the limited data available about the site and the innovative soft solution, the designers and client treated the project as an experiment, with implementation of a thorough monitoring strategy over the design life of the structure. This was to ensure the stability of the system and to document the experiment for future reference.

Key comments from the design report were:

- The slopes of the alluvium on the banks of Dartford Creek were in poor condition, threatening in places the stability of the embankment above.
- The main mechanism for slope instability is toe erosion from the channel flow.
- It was assumed that the rate of failure is slow and that no sudden major slips occurred. This is a design assumption based on previous experience, as reported by Environment Agency operators.
- Erosion of the banks was most prominent on the outside bends of the channel meanders, a result of the natural process of the meander downstream migration. It was estimated that the lateral migration in parts of the site is at a rate of up to 0.5m/year.
- The thickness of the soft engineering profile required is up to 2.5m in places. This is in excess of any previous known application of the technique – about 1.9m thick.

- The viability of the proposed solution depends on the effectiveness of the toe protection system, which will need to be incorporated into the soft engineering.
- Although brushwood is not used as a structural element of the remediated slope, its presence is important throughout its life to discourage erosion near the toe of the slope.
- The brushwood is subjected to regular cycles of wetting and drying, which is likely to decrease its life span.
- Previous remedial works, failed or intact, should not be removed from the site; instead, a construction methodology should be developed that accommodates them in the remediation works, where possible.

8.1.3: Proposed remedial works

The soft engineering solution proposed for Dartford Creek consisted in layers of brushwood bundles laid on top of the alluvial slopes, within a matrix of timber posts driven into the alluvium (see simplified cross section below).

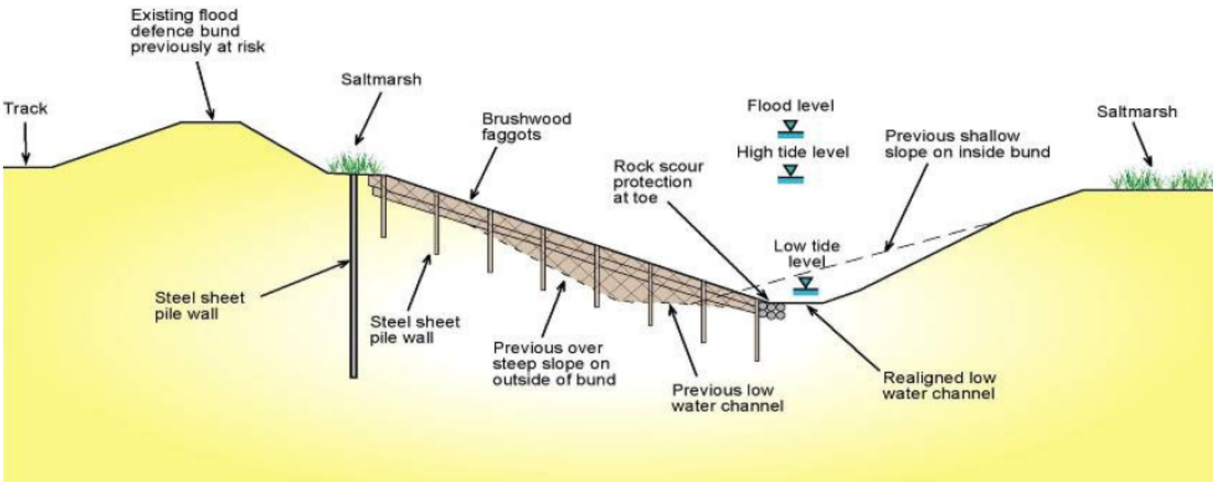


Figure 8.1 – Dartford Creek Simplified Cross Section

The brushwood profiles were held in place by means of a plastic coated wire mesh stapled to the wooden posts. The brushwood was laid in 0.20m thick layers. An equivalent of 10 layers of brushwood bundles were needed to make up the required thickness in some places on this site. The maximum thickness in existing usage of which there was knowledge was 1.9m at Scots Float, Rye, East Sussex; this proposal extended the applicability of this technique. The thickness of the soft engineering profile proposed for this solution was up to 2.5m in places.

The design of the soft engineering aimed to establish a slope gradient of 12°, which has been observed to be a stable natural gradient for the embankment. This is in turn to be improved further by installation of toe protection.

Following instructions from the EA, the sheet pile wall was sized before the design report was compiled in order for the steel to be ordered within the EA financial year 2005 - 2006. This design was based on conservative assumptions.

8.1.4: Further site investigation and design review

In view of difficulties during beginning of site works, the designer decided that a new site investigation was necessary to improve the design parameters for the soil and hence the specified slope geometry for the design. The new ground investigation revealed that the angle of friction of the alluvium was much higher than the previously assumed design parameter of $\varphi = 16.5°$. It was not clear why an apparently clay soil demonstrated such high friction angles, which were of the order of 40° or greater.

For this reason, a more cautious design value was adopted: it was proposed that $\varphi = 25°$ be chosen as a design value for the friction angle of the marsh alluvium. Similarly, the design value of the foreshore Alluvium was chosen to be $\varphi = 18°$ (see Figure 8.2).

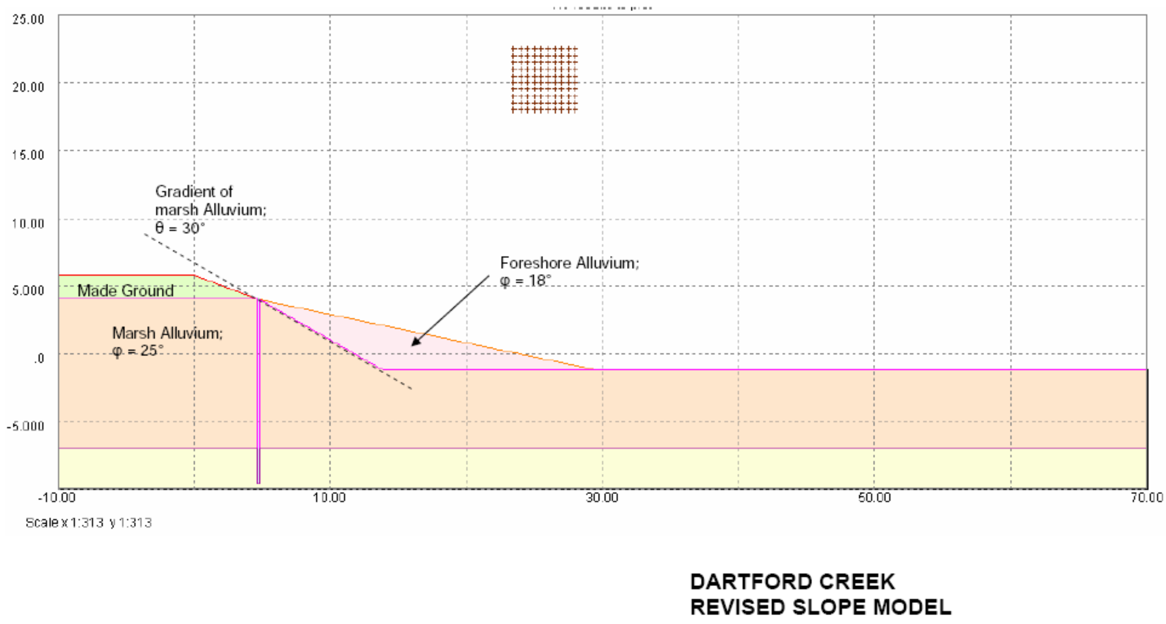


Figure 8.2 – Dartford Creek Revised Slope Model

It was possible that greater slope gradients could be achieved, depending on the actual strength of the foreshore alluvium and the groundwater regime. There was little evidence of this, however, from observation of the existing alluvial slopes and a further increase of the gradient was not considered prudent.

The monitoring strategy, to be followed throughout the life of the project, aimed to both ensure the integrity of the remediation and to document this new type of remediation design.

8.1.5: Assessing the sustainability of the project

To show the potential of the 'GeoSPeAR' methodology in assessing economic, social and environmental aspects of a project and the possibility of improving the sustainability of the design, this project was assessed using three different scenarios, i.e.

(1) A traditional cost driven, low risk geotechnical design approach;

(2) An innovative environmental approach incorporating a combination of ‘hard’ and ‘soft’ engineering approaches, and

(3) A fully holistic sustainable approach chosen to highlight the benefits that can be gained with appropriate foresight.

The methodology of assessments adopted in all three scenarios is the ‘GeoSPeAR’ method discussed in Chapter 7. For this case study the assessment has been done after the completion of the real scenario, assessing the sustainable credentials of the adopted design with the two hypothetical scenarios used for comparison.

8.1.6: Scenario 1

In Scenario 1 it was assumed that a traditional cost driven geotechnical approach was used. This consisted of a sheet piled wall to secure the embankment from possible future collapse. In this case, Step 1 of the methodology was ignored and the briefing did not include the embedment of sustainable values.

For the three scenarios, the boundaries (Step 2) were considered to be the same. The geographical boundary was assumed to be the embankment site and neighbourhood within 5 miles (in order to consider direct effects on community around the site). For social aspects the boundaries included the neighbourhood within which the river and transport links were used. The design and construction performance were compared to normal practice within the business sector in the UK, with supply chain issues not analysed as this information was held by the contractor and not available for this case study.

To collect data for this first assessment (Step 2), the same geotechnical engineer who designed the real option was asked to provide a ‘normal’ design solution to the problem. In this case, the main geotechnical design objectives and all the current UK legislation were fulfilled, but no extra attention was paid to the embedment of environmental or sustainability values into the project.

The assessment (Step 3) was undertaken using 'GeoSPeAR' assessment approach (see Chapter 7 – 7.2.3).

8.1.7: Assessment process

1. Understanding the issues

To obtain a comprehensive understanding of the project and collect data for the assessment the designers where interviewed.

2. Identify stakeholders

All relevant stakeholders, internally and externally, were identified with the help of the designers.

3. Indicator review

The core indicators were reviewed: for each indicator, a worst and best case scenario was identified. The best-case scenario was based on encouraging actions that are beyond current environmental, social and economic best practice. Complying with legislation was not considered the best case as this is something that must be done to comply with the law. Thus complying with legislation was assessed as 0, because projects should be aiming to do better than the basic requirements. Once specified, these were also used as project specific objectives for the three assessments. Best practical environmental options and other best practices were assessed as +2 or +1, (not +3), according to the SPeAR® assessment methodology (Arup, 2007).

4. Data collation

As mentioned above, data were collected from the designers.

5. Workshops

This step of the methodology was not applicable to this case study because client, contractor and other stakeholders were not involved in this assessment.

6. Undertake appraisal

Once all the data were collected an initial appraisal was undertaken. Results are shown in Figure 8.3.

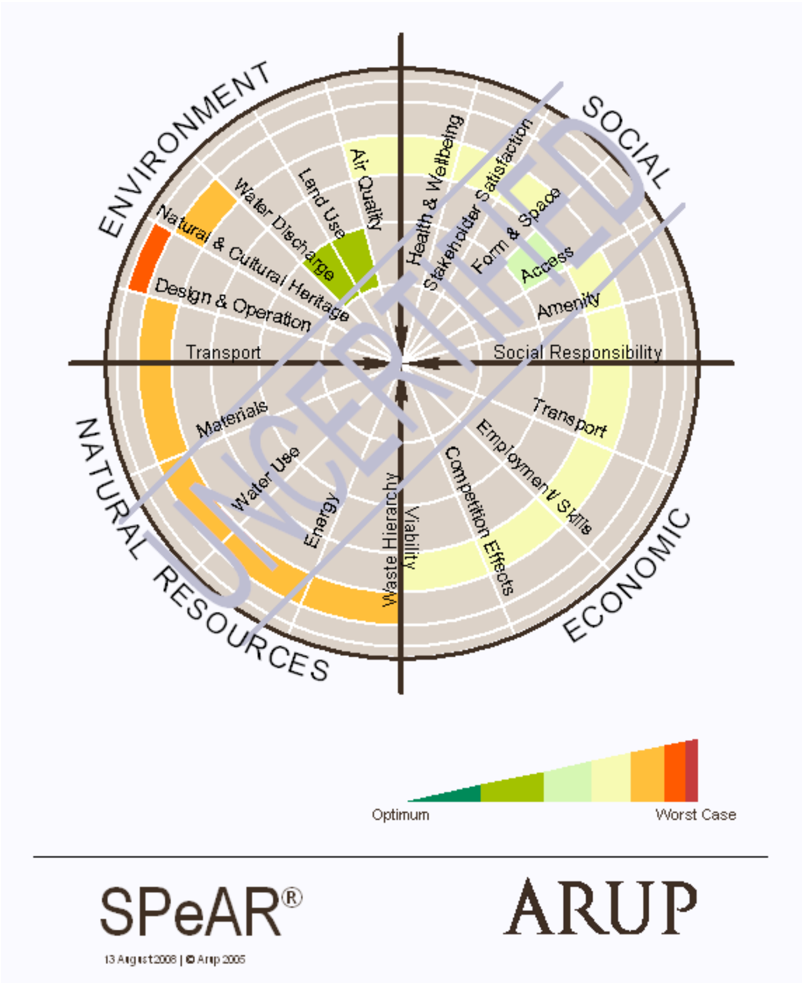


Figure 8.3: 'GeoSPeAR' assessments for case study 1: Scenario 1 - traditional geotechnical design approach.

The 'GeoSPeAR' diagram (Figure 8.3) shows that although 'best' design practice was followed, there is still significant room for improvement in many areas of the project such as design and operation (Step 4).

The lower ratings occurred in the design, environmental and natural resources indicators. This is mostly because sustainable efficiency of the design was not a main priority for the design brief. Also, in this scenario, no further soil investigation was undertaken during the design stage to support improvement of efficiency. Nor was LCA or value engineering carried out at this stage to ensure the best choice of materials and use of natural resources. In addition, no consideration for enhancements to environmental aspects occurred during this scenario, for example protection of biodiversity.

Moreover, no sustainability assessment system was used to support the decision making process during the design and the focus of designers was only to minimise price and programme implications.

As can be seen from Figure 8.3, to embed sustainability and deliver better results, this project would need to be improved in several areas such as design and operation, transport, natural heritage and all natural resources indicators (see Table 8.1 for more information). To achieve this, geotechnical engineers would need to review the design and search for opportunities for improvements in each area (Step 5). Also, the client and contractor would need to agree on improving standards in order to achieve the possible improvements suggested by the designers.

Table 8.1: Summary of opportunities for improvement Case Study 1 - Scenario 1
Design: No sustainability assessment was used during the design process, thus the opportunities to improve sustainability were not discussed in detail. Moreover no life cycle analyses were used during the design process to evaluate choices and quantify impacts of design.
Operation: The diagram shows operation scoring low because there was no real assessment of how to improve sustainability in operation during the design stage. Therefore risks and opportunities were not explored and evaluated as with design.
Transport: Again, no assessment of opportunities to improve sustainability in transport were explored. As this was not a priority for designers the outcomes were below best practice.
Natural heritage: During this first design no special attention was given to improve biodiversity and natural heritage beyond that necessary for planning. Thus there was sufficient room for improvement in the indicators under this section.
Natural resources: Materials, water usage, energy and waste were not priorities in this first design option, thus this should be revised in order to improve the natural resources quadrant.
Other indicators: Moreover all the other indicators could be revised against best sustainability practice in order to improve the overall sustainability of the project.

8.1.8: Scenario 2

For the second scenario, the real design option was considered. In this case, the design brief given (Step 1) by the client focused on finding an innovative, environmental friendly geotechnical solution.

To fulfill the environmentally driven briefing, the client researched the opportunity of using alternative materials. As a result, the solution adopted by the designers was to use a mattress of brushwood faggots to enhance the stability of the river bank, encourage silt accretion and so enhance the salt marsh. To support this design a sheet pile wall was also installed to provide backup to the soft engineering system.

Interestingly in this real scenario, the design was completed at first using a limited amount of desk study and previous ground investigation information, because the client had a very short deadline in which to order materials. The need to order materials before the completion of any further site investigation resulted in a very conservative first design, developed in July 2006. After further site investigation the design was revised and improved in June 2007.

The boundaries (Step 2) were considered to be the same as Scenario 1.

8.1.9: Assessment process

The assessment process was the same as in the first scenario (See Table 8.2). Data was collected from interview with designer, CEEQUAL assessment documentation and design reports (Step 2). With data at hand each indicator was assessed against the 'GeoSPeAR' scale of best and worst case (Step 3). The average performance of each sector was then transferred into the 'GeoSPeAR' diagram. The results of the baseline assessment can be seen in Figure 8.4.

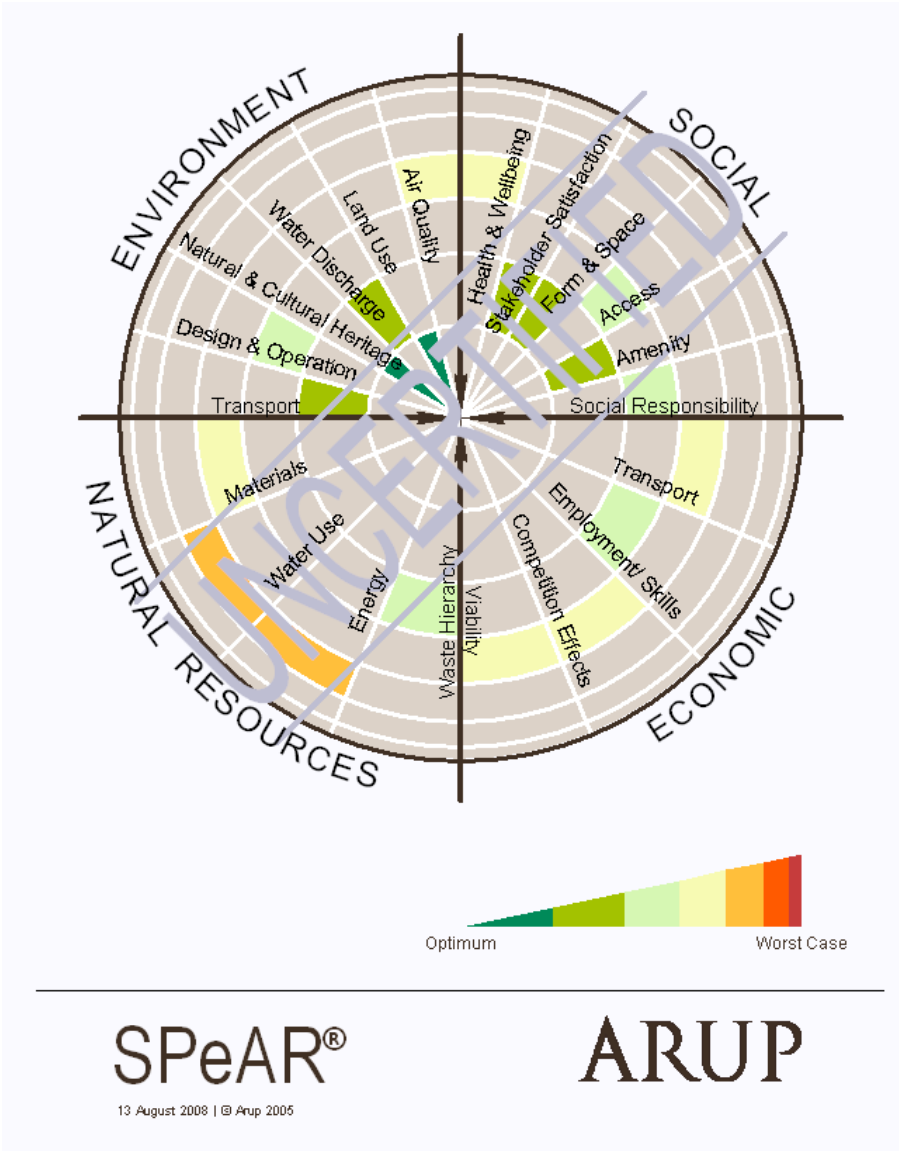


Figure 8.4: 'GeoSPeAR' assessments for case study site: Scenario 2 - environmentally driven approach.

In this scenario it is possible to see how much the client's environmental focus contributed to the changes made to the design brief, improving the overall sustainability of the project. For this scenario the client was specifically interested in the environmental issues of the adopted design and these values were embraced from the beginning of the project. As a direct result a significant improvement towards greater sustainability was achieved by better implementation of existing knowledge and technologies through an innovative design (this can be seen by comparing Figures 8.3 and 8.4).

This clearly shows the difference that the 'soft' engineering together with environmental engineering approach makes, thus allowing the geotechnical designer significantly to enhance the environmental aspects, whilst securing the river banks from erosion. Due to these specific changes made during the design process (such as better use of the river bank to improve natural habitat), the land use, natural and cultural heritage, and design and operation sections of the 'GeoSPeAR' diagram are significantly improved (Figure 8.4). Moreover, indirect benefits were achieved in both the social and economic aspects (reflected in issues such as well being and stakeholder satisfaction) due to the benefits of better environmental management.

However, there is still scope to further improve sustainability aspects (Step 4 and 5) through a change in the natural resources quadrant, despite the waste hierarchy improving due to the use of brushwood material. This is because there was no significant change in the overall use of materials; the sheet pile wall was also necessary to support the main structure. In addition, the purchase of materials before the final site investigation led to an inefficient order of steel, and no LCA and value engineering were used to support material choices in order to reduce natural resource consumption.

However, it should be highlighted that Scenario 2 was an unusual and innovative project example when compared to current geotechnical practice. This clearly shows that 'normal' best practice can be improved with effort and thought. It further shows that the combination of a focused client, in this case primarily through the environmental pillar, and committed consultant can lead to a very different approach to a given geotechnical problem.

Although the second design scenario can be considered more expensive than the first one, (no figures are given due to confidentiality), the client considered that the environmental gains more than offset this extra cost. At present, not every client would be prepared to pay for this offset.

If this scenario was to be further improved achieving a more sustainable outcome, Steps 6 and 7 of the methodology would be helpful in supporting design decision making.

Table 8.2: Summary of opportunities for improvement Case Study 1 - Scenario 2
Design: Although the design has been revised with environmental issues as priorities, there is still room for assessing and improving other indictors on all four quadrants. No life cycle analysis carried out in this scenario, this could improve even more the design decision making process.
Natural resources: Again not much attention was given to improvement of natural resources usage such as energy and water. Although there is some visible improvement under this quadrant due to the change in materials specification, there is still room for improvement. Moreover waste was reduced because of improvement on materials specification but not by improving design or construction processes. Thus there is still room for improvement under this indicator.
Transport: Transport has been improved under the environmental quadrant due to fact that most of the materials would be transported to site via water ways such as canals and rivers reducing CO_2 emissions and traffic. However no further comparison was made into different option of aquatic transport to understand how CO_2 could be reduced even further.
Other indicators: As in the first scenario not much attention was given to important indicator such as air quality, health and wellbeing and competition effects. Thus these should be revised.

8.1.10: Scenario 3

In this scenario an extreme holistic approach to sustainability was assumed to have been taken using 'GeoSPeAR' as a support tool for design. Therefore during the briefing stage (Step 1) questions such as, 'How much water does it use? How much energy does it need? Where does the energy come from? Can we use recycled materials? Are all the materials sourced in a socially responsible way?' would have been asked to challenge designers to think about decisions and how one early choice, of material for example, can lead to different outcomes throughout the process. This is because a holistic sustainable approach ensures that the key questions are asked in all the important design stages to ensure that either damage is reduced or benefits are made in every step of the process across all the pillars (Dickson, 2002).

The boundaries (Step 2) were considered to be the same as in the Scenarios 1 and 2. The data collected (Step 2) came from asking the designer and sustainability specialists to consider a more holistic sustainable solution embedding the 'GeoSPeAR' methodology into the design making process.

The third scenario gave equal consideration to all issues as far as was practicable. Such an approach encourages innovation and frees up the designer by not initially imposing constraints, which can afford greater flexibility and a much broader range of successful benefits. This approach does not automatically result in added costs as these potentially could be offset by the gains made in efficiency, as demonstrated by Phear *et al.,* 2003.

Although the objectives of the project in Scenario 3 were in essence similar to the second scenario there are the additional requirements to improve sustainability by engaging with the contractor, minimising the use of natural resources and maximising the social and economic benefits though sustainable procurement. Also in this scenario the 'GeoSPeAR' assessment would be used to aid the designer within the decision making process from the beginning making sure that all the suitable questions were asked before choices were made.

Once all the data was collected an appraisal was undertaken (Step 3) using the 'GeoSPeAR' assessment approach (see Chapter 7 – 7.2.3).

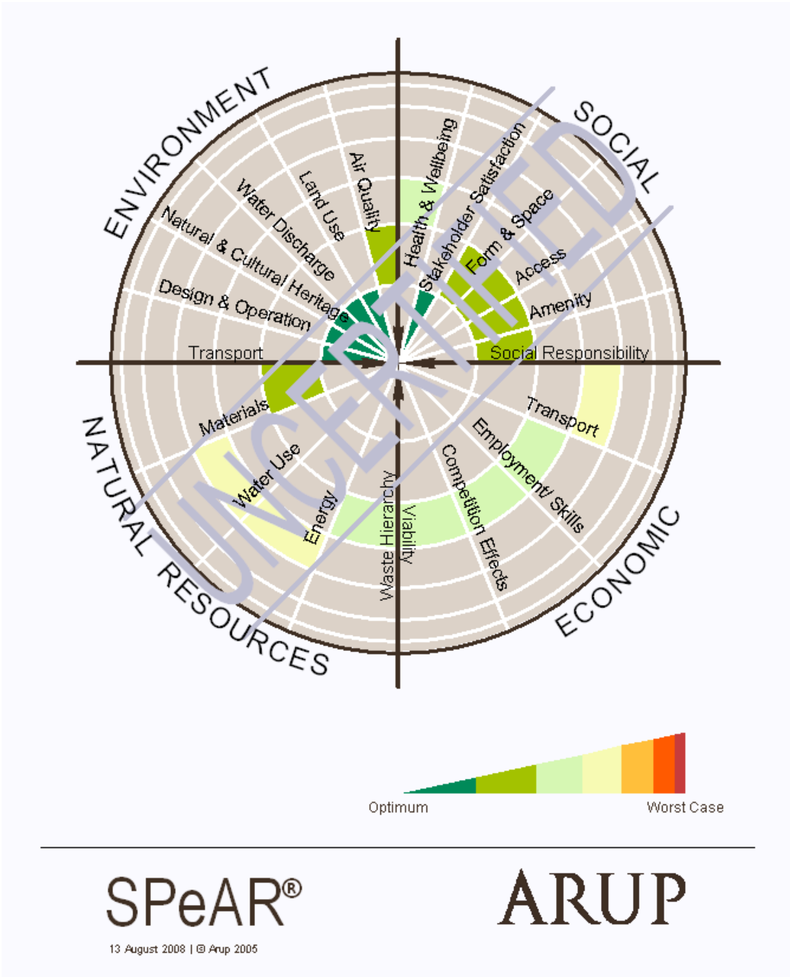


Figure 8.5: 'GeoSPeAR' assessment for case study site: Scenario 3 - fully holistic sustainable approach.

The outcome from the sustainability design 'GeoSPeAR' assessment is illustrated in Figure 8.5. This shows the potential improvements in sustainability, especially in the social aspects and natural resources quadrants, together with improvements in the economic quadrant, e.g.

through enhancements in competition effects and viability.

The key difference in this third scenario was the more focused approach to sustainable design and the assessment of opportunities for improvement. This approach encourages geotechnical designers to assess the strengths and weaknesses of each design option (Step 4). This allows the designer to rethink their methods, improving social, environmental and economical aspects (Step 5).

In addition the use of an assessment tool increases the need for the designer to liaise closely with the client, contractors and sustainable advisers to ensure that there is transparency and common understanding of the sustainable approach in every decision. This would improve lines of communication between different sectors of the industry facilitating the discussion about sustainable options for geotechnical engineering.

The improvement in the natural resources quadrant came by a less conservative approach at the design stage and an overall improvement of the design process by the embedment of sustainable values. In addition, this could be helped and improved by responsible procurement of materials and by using energy from sustainable sources during the construction and production of materials phases. Moreover, the efficiency of the design could be improved by using a process such as BIM (Building Information Modeling) to improve design management and efficiency throughout construction (Autodesk, 2010).

Another important issue is the site investigation. In this case it can clearly be seen how important further site investigation was and how it could have helped the designer if it had been carried out before the first design. A specific improvement would have been to order the materials after the final design to avoid the waste of materials by over ordering.

Air quality was improvement by the specification of tools and equipment that have been picked for their superior environmental performance. Competitive Effects was improved considering that the project would became as case study for marketing material, presentation and discussion with clients and suppliers about other work opportunities. Health and wellbeing was improved by the improvement of the tools and equipment reducing, noise, vibration and emissions whenever possible as much as possible.

A cost difference between the second and the third design scenarios are likely to exist due to the extra time needed for the detailed sustainability assessment to take place during the design process. Also, extra time would be needed to meet and properly engage with the contractor and the client in improving the sustainability of the design and specification of the project. Other extra costs could come from procuring ‘greener’ energy and more sustainable materials, tools and equipments such as ‘green temporary cabins’. However, these improvements will not always be possible given that not all clients are willing to increase the budget in order to deliver a more sustainable outcome.

However, extra costs incurred by better design in the third scenario could potentially be offset by savings in materials, energy, transport and waste reduction. Also, cost could be reduced by claiming research and development tax relief for some of the costs of the design and construction, once this project was considered a research experiment (DTI, 2004).

Additional cost offsets could include improvement in the brand image of the companies involved in the project (client, designer and contractor) and potential marketability through a sustainable project profile, allowing all involved to play a significant leadership role within the construction industry in the future (DeSimone and Popoff 2000; Bleischwitz and Hennicke, 2004).

8.1.11: Implications

At present, Scenario 1 (conservative geotechnical design complete without too much attention to sustainability issues) is predominantly in use in the UK. Scenario 2 is a unique example where there are clients and consultants in the market place ready to take a chance and use new knowledge and technologies to improve the design and environmental performance. Scenario 3 is the ideal scenario that theoretically can be achieved and is becoming the guideline for model projects such as the London 2012 Olympics Park in London, where the client is pushing significantly in favour of sustainability (Cole and Lynch, 2010).

The 'GeoSPeAR' assessment exposes the differences between the three scenarios and allows for effective flexible assessment of sustainability within the different geotechnical options. More importantly, this approach allows alternative options to be assessed and progress checked, through the embedment of the key advantages contained within 'GeoSPeAR'. This provides a flexible assessment approach using a simple format that can be used to assess geotechnical projects.

For the first case study the LCA element of 'GeoSPeAR' was not introduced, although combining LCA with the 'GeoSPeAR' assessment allows better support and greater robustness for some indicators such as embodied energy, carbon, materials and water use. However, LCA tools will not always be available to designers. Thus it is important to highlight that it is not imperative to use LCA to assess the overall sustainability of a project, but that the use of this support tool can improve transparency and understanding of the 'cradle to grave' effects of the project (Keeler, 2009). The use of LCA with 'GeoSPeAR' will be demonstrated later in this Chapter (see 8.3.6).

It is also important to mention that this project achieved such positive scores on 'GeoSPeAR' due to the nature of the project. Because an embankment project by itself represents a good improvement to the environment and local community the project scores well against many indicators. However, even a project like this could not score all 'green' on the 'GeoSPeAR' diagram because every project has its weaknesses and limitations.

Thus, the key to continuously improving sustainability is to understand where the real limits of specific projects are and how these limits can be overcome. This is why, in contrast to other methodologies, the 'GeoSPeAR' assessment system does not have a pass or fail score, because it acknowledges that every project will have its own limits to sustainability.

Overall the analysis of this first case study highlighted the immense potential to improve sustainability of current normal geotechnical design. It also shows the opportunity for designers in embracing new solutions to well known problems in order to achieve better sustainability.

If the scenarios above were to be further improved Steps 6 and 7 of the methodology would need to be followed, in order to guide designers during the decision making process towards sustainability (this will be demonstrated on Case Study 2).

Moreover, key to improving sustainability is the consideration of how to enhance and influence the actual construction process. Often designers have little influence on this, particularly with regard to decisions about resource management and waste related decisions during construction. This was reflected in no significant change in key sectors related to natural resources, such as energy use, during all three scenarios. A natural improvement to this would be to engage earlier with contractors and to improve interaction between consultants, clients and contractors to enhance sustainability through improved efficiency on site as well. At an early stage these considerations could significantly enhance both environmental and social management during geotechnical projects.

8.2: CrossRail

For the second case study a tunneling project was chosen. This was to demonstrate how the use of 'GeoSPeAR' at early stages can influence geotechnical engineers in rethinking even the most established solutions.

In this example, the same design option will be assessed twice in order to demonstrate how the embedment of sustainability values would make a difference to the outcome of the same design solution. The first assessment will consider the normal low risk 'price and programme' focused design option. This is to highlight where unsustainable choices were made and where the hidden opportunities for improvement of the project are.

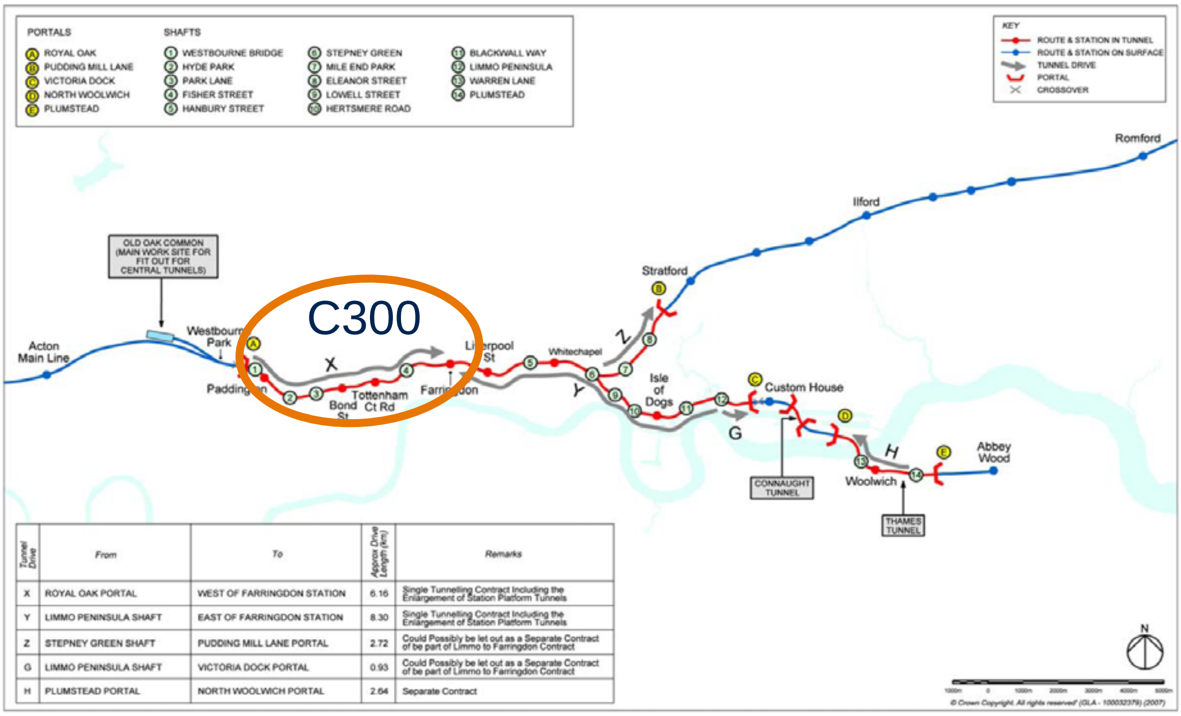
Considering the results from the first assessment, weaknesses of the design will be revised and improvements suggested. A second assessment will be undertaken to compare the improved solution with the original one and to demonstrate the improvements that could have been made if sustainability was a main priority at the design stage.

In contrast to the first case study, this project will be assessed at the early design stage before the construction of the project. In this case, because the project has not yet been built the two assessments were conducted using hypothetical data. Thus, it should be noted that all the design decisions assessed are dependent on assumptions. However, this should not be seen as a limitation of the assessments because the objective of this exercise is to illustrate how 'GeoSPeAR' can help and influence designers to rethink their decisions and improve sustainability before development of the detailed solution.

8.2.1: Overview of the project

The case study relates to one of the main tunnels of the Crossrail scheme to be constructed in London. The Crossrail project includes 42km of new tunnels underneath Central London, 37 stations, with eight new central London stations and 28 upgrades of others. The complete project will allow passengers to travel from stations in Berkshire, Essex and the borders of Kent into Central London - without the need for people to get off and catch the Tube or bus. With a total budget of £15.9 billion, Crossrail is scheduled to be complete by 2017.

The Package C300 Tunnels West comprises the construction of twin 6.2m diameter bored tunnels from Royal Oak Portal (west of Paddington Station) through to the new Crossrail Farringdon Station, with a length of drive of approximately 6.2km including a crossover at Fisher Street (see Figure 8.6).



Tunnel Drive	From	To	Approx Drive Length (km)	Remarks
X	ROYAL OAK PORTAL	WEST OF FARRINGDON STATION	6.16	Single Tunnelling Contract Including the Enlargement of Station Platform Tunnels
Y	LIMMO PENINSULA SHAFT	EAST OF FARRINGDON STATION	8.30	Single Tunnelling Contract Including the Enlargement of Station Platform Tunnels
Z	STEPNEY GREEN SHAFT	PUDDING MILL LANE PORTAL	2.72	Could Possibly be let out as a Separate Contract of be part of Limmo to Farringdon Contract
G	LIMMO PENINSULA SHAFT	VICTORIA DOCK PORTAL	0.93	Could Possibly be let out as a Separate Contract of be part of Limmo to Farringdon Contract
H	PLUMSTEAD PORTAL	NORTH WOOLWICH PORTAL	2.64	Separate Contract

Figure 8.6: C300 route through Central London

The scope of the C300 project includes:

- Construction of the western section of the Crossrail running tunnels (6.2m ID) between the Royal Oak Portal and Farringdon Station (Drive X on Figure 8.6)
- Going through:
    - Paddington Station
    - Bond Street Station
    - Tottenham Court Road Station
- Construction of the Fisher Street Shaft & Cross Passages
- Construction of 6 cross passages, 3 sumps and 2 niches with sumps
- Manufacture of precast concrete segments for tunnels
- Transportation of all excavated material by rail

8.2.2: First assessment

For the first assessment it was assumed that a traditional cost driven geotechnical approach was used. Thus, no further consideration was given to evaluate the sustainability of the project during the design stage. In this scenario the main brief given to designers focused on improving 'price and programme' and respecting all the UK legislation, in particular the Crossrail Act. The Crossrail Act is a document passed by Parliament and issued by Crossrail with all the specifications for the project such as limits on noise and vibration levels and other specific issues related to such a unique project in Central London, e.g. traffic, historic buildings and interfacing with tube stations.

Thus, in this scenario, Step 1 was ignored and the brief to the designers did not include the embedment of 'GeoSPeAR' assessment. The main geotechnical design objectives were fulfilled, but no extra attention was considered to the embedment of sustainability values into the project.

The boundaries for the two assessments (Step 2) were considered to be the same. Geographical boundaries were assumed to be the tunnel site and neighborhood within 5 miles. For social aspects the boundaries included the neighbourhood within the tunnel (within 5 miles) and transport links to and from sites. The design and construction performance were compared to normal practice within the business sector in the UK, with supply chain issues analysed at first level considering that the contractor would be willing to interact with the designers, suppliers and sub-contractors.

The main data were collected from the Crossrail library (on line) and other Crossrail documents within the public domain, such as the Crossrail Act (HM Government, 2008), together with interviews and workshops with designers and contractors (Step 2).

Assessment Process

The assessment (Step 3) was done using 'GeoSPeAR' according to the 'GeoSPeAR' assessment model (Chapter 7 – 7.2.3).

1. Understanding the issues

To obtain a comprehensive understanding of the project and collect data for the assessment the document describing the project were reviewed. Also possible designers and contractors were interviewed.

2. Identify stakeholders

All relevant stakeholders, internally and externally were identified with help of possible designers and contractors.

3. Indicator review

The core indicators were reviewed in the same way as in the first case study. For each indicator a best and worst scenario was identified. The best-case scenario was based on encouraging actions that are beyond current environmental, social and economic best practice. Complying with legislation was not considered the best case as this is something that must be done to comply with the law. Thus complying with legislation was assessed as 0, because projects should be aiming to do better than the basic requirements. Once specified, these were also used as project specific objectives for the three assessments. Best practical environmental options and other best practices were assessed as +2 or +1, (not +3), according to the SPeAR® assessment methodology (Arup, 2007).

4. Data collation

Data were collected from the Crossrail documents, interviews and workshops with possible designers and contractor.

5. Workshops

The researcher attended many workshops relating to the planning of design and construction of the project. At these workshops design options were discussed, providing useful data for the assessment.

6. Undertake appraisal

Once all the data were collected an initial appraisal was undertaken. Results are shown in the diagram below (Figure 8.7).

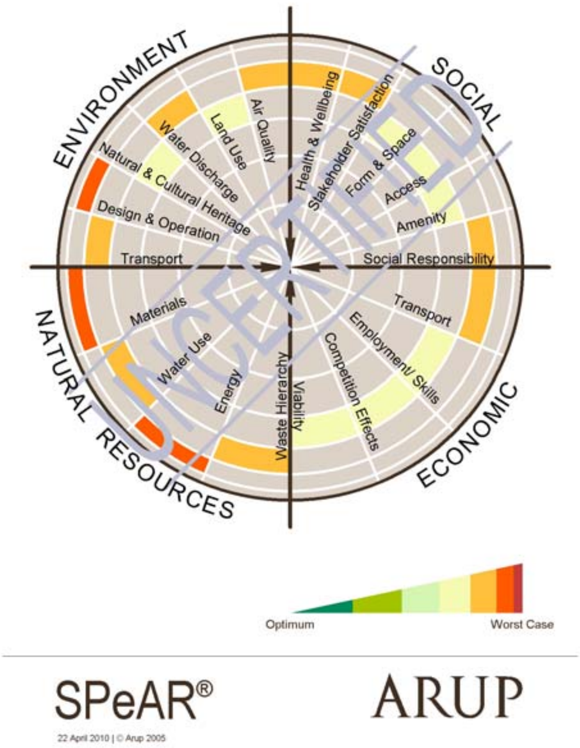


Figure 8.7: 'GeoSPeAR' assessments for case study 2: Scenarios 1 – traditional geotechnical design approach

In this diagram it can be see that the traditional cost driven geotechnical approach ignores many opportunities to improve environmental, social and economic aspects. Therefore the diagram highlights opportunities for improvement in most sectors of the diagram. Particular issues to be reconsidered in this project would be design, natural resource indicators (materials, water usage, energy and waste), water discharge, transport, health and wellbeing, stakeholder satisfaction and social responsibility.

Analysing these indicators individually many opportunities for improvement can be highlighted (Step 4).

Design: In this traditional and conservative scenario the design team would not have considered environmental and social issues in depth. Therefore, this would be the main area for improvement in the design. Also, as design decisions influence other areas of the diagram, without the embedment of sustainable values at this stage a negative ‘domino effect’ can be created affecting other indicators. Therefore during design, consideration needs to be given to overarching decisions that govern energy, resources, environmental quality and social aspects and other sustainability issues. Furthermore, it is necessary to consider design variables as a unified whole and use them as problem solving tool to improve the sustainability of the project in order to achieve a more sustainable outcome (Keeler *et al.*, 2009). Also life cycle analysis could be used to support decision making.

Natural resources (materials, water-use, energy, waste hierarchy): Tunneling projects can consume large amounts of natural resources during construction. The excavation process itself is very energy demanding due to electricity and fuel required by the tunnel boring machine (TBM) and also because large amounts of energy, materials and water are required to produce the concrete segments needed to support the tunnel (in this specific project). In addition, large amounts of fuel are used to transport materials to and soil from the site.

In a traditional design, although consideration is normally given to material reduction in order to reduce costs, many opportunities for reducing, reusing and recycling natural resources further are missed due to lack of further analysis of material life cycle and embedded impacts. Also if a resource, such as water, does not considerably change the budget, due to current low market value, very little attention is given into reducing its use with no consideration given to the environmental and social impacts of this decision. Thus, attention needs to be given to every decision about resource use if sustainability is to be embedded into the design.

Water discharge and water pollution: This specific design interferes with the main aquifers in London, therefore dewatering will be part of the programme at several points of the tunnel.

This means higher risk of geotechnical difficultness. Moreover, going through the aquifers increases risk of water pollution and aquifers contamination, especially affecting the London Basin Chalk Aquifer. Hence, if measures to conserve water quality and reduce water consumption of the complete project are not considered and incorporated into the design there is a high risk of an unsustainable outcome in this area.

In this first approach, consideration would be given to understanding the water implications for the geotechnical works, however no further investigation would be made into addressing environmental and social implications of the water issues for the project.

Transport: As the main portal of the tunnel is at Royal Oak, in Central London, the logistics of bringing materials in and waste and soil out of the site need to be carefully considered. Great attention needs to be given at the design stage to ensure that materials are specified in a way that considers transport needs. Without carefully analysing logistics at this stage, considerable traffic and emissions can be generated during construction disturbing both the environment and the community.

Again, designers would tend to give little consideration to these issues during design stage in a conservative approach, as normally logistics would be considered to be a 'problem' for the contractors. However, designers have a huge opportunity to influence logistics if considering all the demands that their design options represent to the transport needed during construction.

Health and wellbeing: Health and wellbeing will be linked to indicators such as air quality, materials, energy, stakeholder satisfaction and social responsibility. Therefore when these indicators are not scoring well the need for improvement will also be reflected on the health and well being indicator.

In a traditional approach engineers would assume that by complying with environmental and health and safety legislations this subject would be completely covered. However, a wider assessment of the issues affecting this indicator will show that further improvement can be achieved by careful consideration of materials, tools, equipments and processes selection.

As an example, a simple action above legislation such as specifying non hazardous paints, solvents, greases and other materials whenever possible can considerably reduce the risk for human health on sites improving the health and wellbeing of workers.

Stakeholder satisfaction: As with health and wellbeing, this indicator is a reflection of the performance of other indicators such as noise, vibration, air pollution and transport because careful consideration of these indicators will support better stakeholder satisfaction. This is because the indirect link between many indicators. Therefore, considering that this scenario has a traditional approach resulting in low scoring in many indicators it is not surprising that stakeholder satisfaction also scored low. Thus, general embedment of sustainability will be needed to change the results in the stakeholder satisfaction indicator.

Social responsibility: As it can be seen from the analysis of the indicators above, there are many social issues related to a geotechnical project. Therefore this indicator will reflect the degree to which geotechnical engineers have addressed the social issues of the project and have acted with responsibility when considering their choices throughout the design.

In a traditional approach little attention is given by designers to social, ethical and global issues related to the geotechnical project and as a result many choices are made without consideration to the social impacts of these choices. This is because there is still a general belief that social issues are normally analysed and addressed by other professionals in the construction chain such procurement management and therefore geotechnical designers are free from dealing with social implications. However, to support and improve social responsibility the choices made at all levels of the project, including geotechnical design, need to be carefully considered. Ideally all the supply chain should be assessed for environmental and social impacts and certified by standards such as ISO 14001, ISO 9000 and BS OHSAS 18001.

Pollution: Analysing why indicators such as air quality, water discharge, transport, health and wellbeing and social responsibility scored low will allow an understanding of overarching themes such as pollution contributing to performance under more than one indicator. This is because each material, equipment and process has a life cycle pollution footprint which affects the whole sustainability of the project.

Also during construction the pollution produced on site can influence the environment outside and inside the tunnel, affecting the health and wellbeing of employees and communities around the sites. Largely the site issues have been covered by environmental and health and safety legislation. However, there is still opportunity for designers to reduce the cumulative pollution footprint of a project by understanding the life cycle of materials, processes and products, and by collectively reducing the hidden critical impacts such as CO_2 emissions, whenever possible.

8.2.3: Considerations and improvements

As can be observed from the first 'GeoSPeAR' assessment (Figure 8.7) and the associated considerations, the C300 stage of Crossrail could be improved in many areas if designers considered the outcomes of their decisions more deeply and work on mitigating their effects on environment, society and economy.

More importantly the 'GeoSPeAR' analysis represents graphically where the main opportunities for improvements are, giving designers direction to focus on the major issues to be addressed. Consequently in order to improve design options and achieve more sustainable outcomes, consideration needs to be given to all the indicators that scored poorly.

In this way the design can be revised and improved, indicator by indicator (if conflicts between indicators are carefully managed), with overall improvement as the main objective (Step 5). Moreover, bigger improvements can be made if the client, designers and contractors come together at the design stage to analyse the 'GeoSPeAR' assessment and work as a team to improve the sustainability of the solutions.

In this specific case study, the review of design does not result in changes to the main design solution (as in the first case study). However, considerations would be given to improve the smaller choices made around the main design. This shows how important these 'smaller choices' are and how the final outcome of the project can be changed by these, without major changes in the overall design.

Thus, to embed sustainability into the main design, the highlighted issues discussed above would be revised and improved whenever possible.

Design: To reduce and improve social, environmental and economical impacts engineers need to consider fully the outcome of their design options from early stages. Thus, designers need to assess and understand potential risks, weaknesses and opportunities for environmental enhancements associated with social issues and economical efficiency. This is because every design decision produces a cascade of multiple effects, rather than an isolated impact, and successful integrated sustainable design requires understanding of the interrelationship of each aspect of sustainability (Keeler and Burke, 2009).

Therefore, to practically achieve this, design options need to be assessed against a sustainability system of indicators (such as ‘GeoSPeAR’) during the decision making process. To help with this assessment, tools such as carbon calculators (EA, 2009) and Life Cycle Analysis (this will be demonstrated further) can be embedded into the assessment to quantify some of the ‘cradle to grave’ impacts and effects of design providing some quantitative data to support qualitative decision making. This allows carbon critical design to be considered (Clarke, 2010) within a holistic sustainable assessment view.

This process needs to occur at the first stages of the decision making process because this is where designers have major opportunity to influence the whole project and its impacts, materials, methods and specification influencing procurement and works on site. After the design stage and specification are completed the opportunities for embedding sustainability are considerably reduced, although still not completely lost.

Therefore, to improve the sustainability of this design option, a ‘GeoSPeAR’ assessment should be carried out by the designers to highlight the opportunities for improvements. After that, major weaknesses of the design should be revised and improved. This will now be illustrated.

Natural resources (materials, water-use, energy, waste hierarchy): To improve natural resource consumption it is necessary to improve materials, energy and water efficiency. To understand how better to be effective in reducing natural resources consumption it is important to know where the main impacts are hidden and where the main gains can be made.

As an example, on this project 73,200m^3 of concrete will be specified at the design stage to produce the segments needed for the tunnel. Normally the concrete is defined by technical specification only, considering the strength of the concrete. However using LCA (using SimaPro) to calculate some environmental impacts of the production of concrete, designers can understand the embedded energy in the concrete production and the main differences in CO_2 production between different concrete mixes (see Figures 8.8 and 8.9 and Tables 8.3 and 8.4). By using a professional LCA tool such as SimaPro, designers have the opportunity to use a complex database with thousands of processes plus the impact assessment method. Also it gives them the ability to collect, model and monitor environmental impacts numerically in order to support qualitative analysis.

Table 8.3: Carbon emissions from Concrete, with ground Granulated Glastfurnace Slag (GGBS) cement replacement - typical dry batch weights Kg/m^3 (SEESA, 2010).

Table 8.3: Carbon emissions from Concrete, With GGBS Cement Replacement - Typical Dry Batch Weights Kg/m^3 (SEESA, 2010)

Mix No	Description	Strength Class	W/C Ratio	CEM I	GGBS	Sand	4/10mm	10/20mm	WRA	Super Plas	AEA	Water	Density kg/m3	% GGBS	CO2e kg/m3	% reduction in CO2e
1	GEN3	C16/20	0.59	168	103	757	363	750	0.00	0.00	0.00	160	2301	38	219	15.12
2	RC25/30	C25/30	0.51	176	108	744	364	752	1.42	0.00	0.00	145	2290	38	228	15.24
3	FND2	C25/30	0.47	190	130	777	331	773	1.60	0.00	0.00	150	2353	41	250	16.67
4	FND3	C25/30	0.40	246	151	619	362	748	1.99	0.00	0.00	159	2287	38	303	16.07
5	PAV2	C28/35	0.41	228	139	617	343	710	1.84	0.00	0.44	150	2190	38	282	16.07
6	RC28/35	C28/35	0.48	188	115	724	364	753	1.52	0.00	0.00	145	2291	38	241	15.44
7	RC28/35 (pump)	C28/35	0.48	216	132	728	332	687	1.74	0.00	0.00	167	2264	38	271	15.84
8	C28/35 DC3	C28/35	0.40	246	151	619	362	748	1.99	0.00	0.00	159	2287	38	303	16.07
9	C28/35 DC3 (pump)	C28/35	0.40	290	177	591	328	678	2.34	0.00	0.00	187	2253	38	351	16.03
10	C32/40	C32/40	0.41	220	150	726	334	780	1.85	0.00	0.00	152	2364	41	283	17.01
11	RC40/50XF	C40/50	0.42	257	157	661	335	693	0.00	2.49	0.00	174	2279	38	316	15.96

Table 8.4: Carbon emissions from concrete, without cement replacement - typical dry batch weights Kg/m^3 (SEESA, 2010).

Table 8.4: Carbon emissions from concrete, Without Cement Replacement - Typical Dry Batch Weights Kg/m3 (SEESA, 2010)

Mix No	Description	Strength Class	W/C Ratio	CEM I	GGBS	Sand	4/10mm	10/20mm	WRA	Super Plas	AEA	Water	Density kg/m3	% GGBS	CO2 e kg/m 3
1	GEN3	C16/20	0.59	271	0	757	363	750	0.00	0.00	0.00	160	2301	0	258
2	RC25/30	C25/30	0.51	284	0	744	364	752	1.42	0.00	0.00	145	2290	0	269
3	FND2	C25/30	0.47	320	0	777	331	773	1.60	0.00	0.00	150	2353	0	300
4	FND3	C25/30	0.40	397	0	619	362	748	1.99	0.00	0.00	159	2287	0	361
5	PAV2	C28/35	0.41	367	0	617	343	710	1.84	0.00	0.44	150	2190	0	336
6	RC28/35	C28/35	0.48	303	0	724	364	753	1.52	0.00	0.00	145	2291	0	285
7	RC28/35 (pump)	C28/35	0.48	348	0	728	332	687	1.74	0.00	0.00	167	2264	0	322
8	C28/35 DC3	C28/35	0.40	397	0	619	362	748	1.99	0.00	0.00	159	2287	0	361
9	C28/35 DC3 (pump)	C28/35	0.40	467	0	591	328	678	2.34	0.00	0.00	187	2253	0	418
10	C32/40	C32/40	0.41	370	0	726	334	780	1.85	0.00	0.00	152	2364	0	341
11	RC40/50XF	C40/50	0.42	414	0	661	335	693	0.00	2.49	0.00	174	2279	0	376

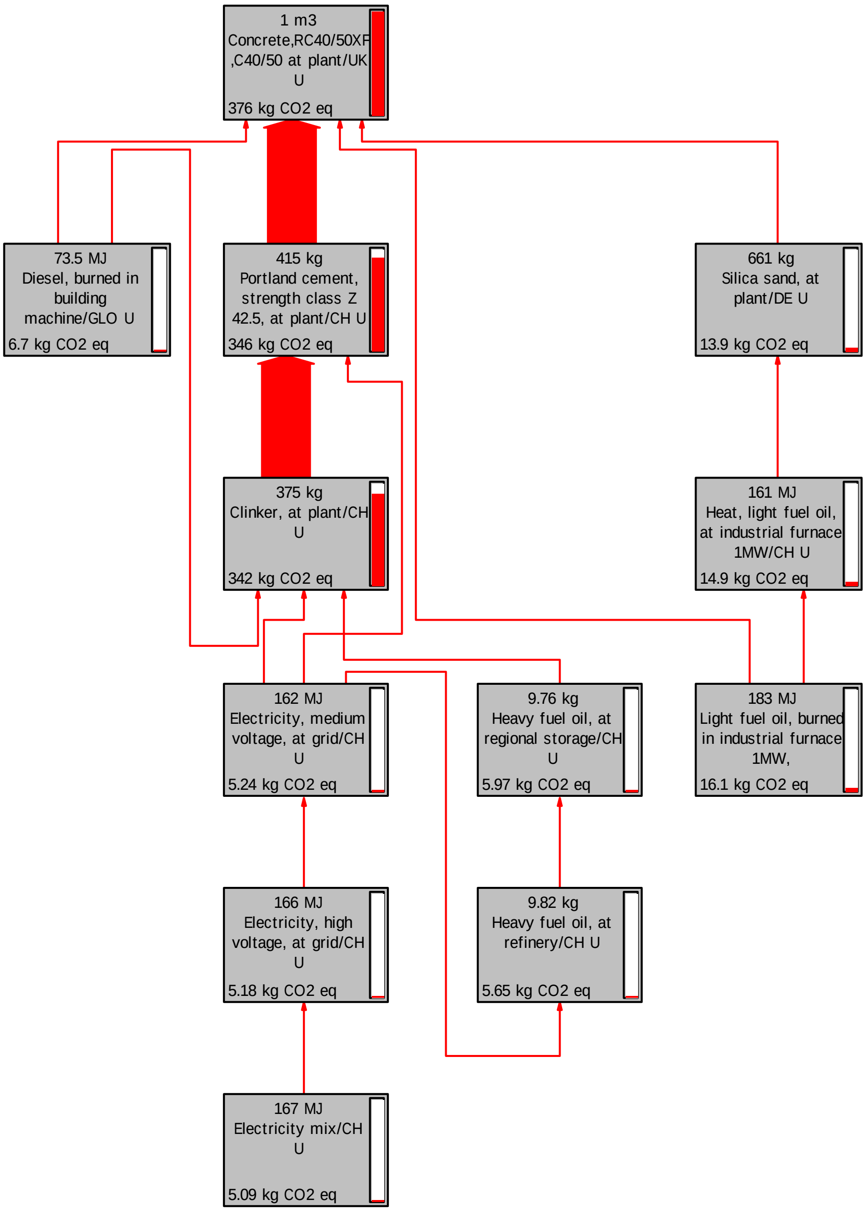


Figure 8.8: Embedded energy consumption Mix 11 without cement replacement (see Table 8.3)

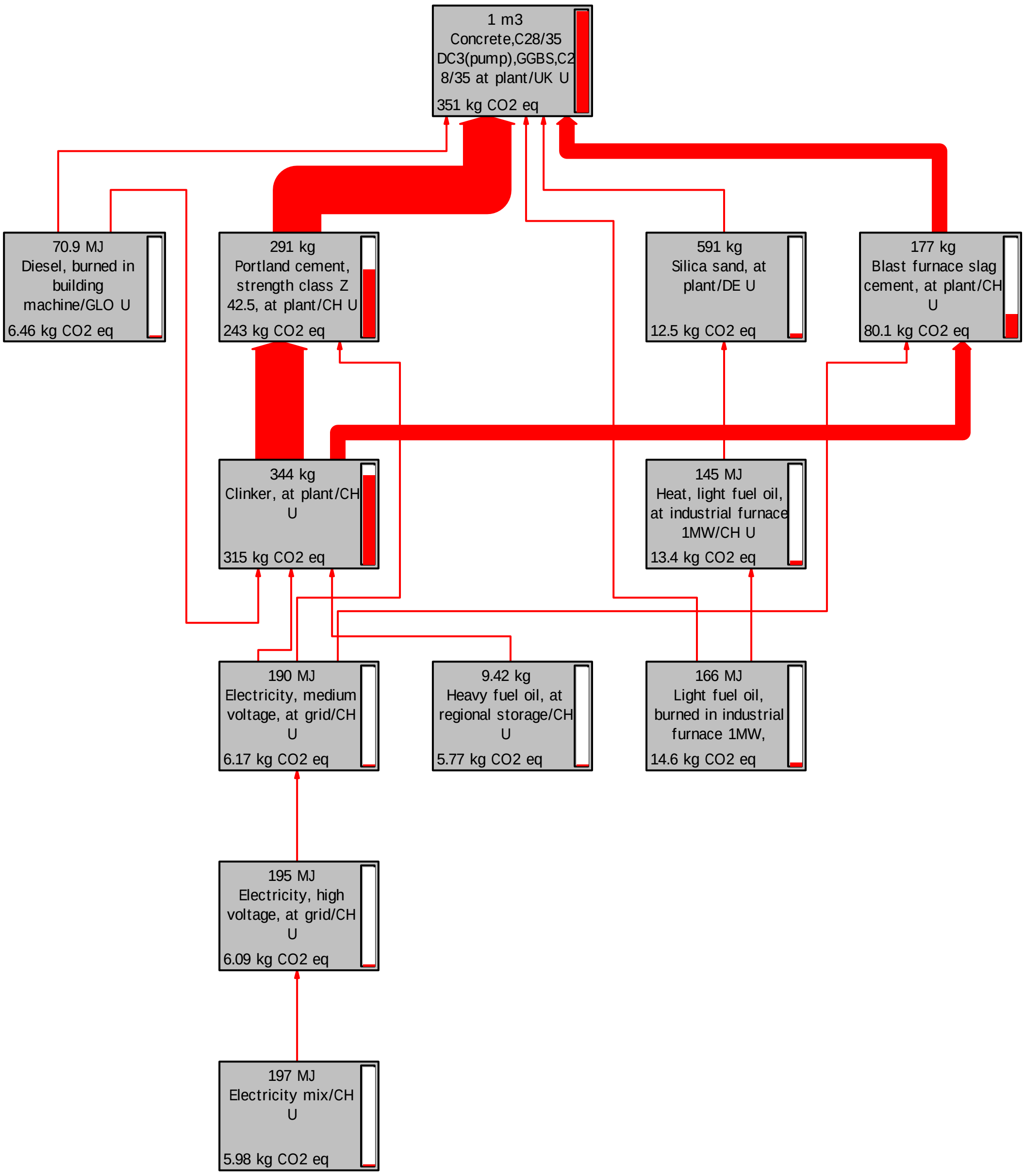


Figure 8.9: Embedded energy consumption Mix 9 with GGBS as cement replacement (see Table 8.4)

As can be seen from the Tables 8.3 and 8.4 and Figures 8.8 and 8.9, different mixes have different embedded energy consumptions and therefore different CO_2 emissions as a result of replacing high energy products such as Portland Cement by lower energy products such as Ground Granulated Blastfurnace Slag (GGBS).

By calculating the CO_2 production of different concrete mixes it can be seen how the embedment of GGBS has an impact in reducing CO_2 of concrete. With this data at hand designers can better understand and compare different design specifications (see Figure 8.8 and 8.9). Although CO_2 cannot be considered as a measure of sustainability it can be considered as a good indicator for energy consumption and climate change impact. By tackling carbon production in this way, designers can start to reduce environmental impacts, supporting an overall improvement in sustainability (Clarke, 2010).

Therefore, 73,200m^3 of concrete for Mix 9 (with GGBS as cement replacement) produces 25,693,200kg of CO_2 and for Mix 11 (without cement replacement) produces 27,523,200kg of CO_2. This demonstrates that a change in concrete specification represents a saving of 1,830,000kg CO_2 and thus reduction in embodied energy for the project. Moreover, by using recycled material (GGBS) as a substitute for Portland Cement the natural resource demand was reduced and the waste sent to landfill was also reduced (see Table 8.5).

Table 8.5: Comparison between GGBS and CP environmental impact (Higgins, 2006).

Environmental Issue	Measured As	Impact	
		One tonne of GGBS[1]	One tonne of PC
Climate change	CO_2 Equivalent	0.07 tonnes	0.95 tonnes
Energy use	Primary energy[2]	1,300 MJ	5,000 MJ
Mineral Extraction	Weight Quarried	0	1.5 tonnes
Waste disposal	Weight to Tip	1 tonnes saved[3]	0.02 tonnes

Notes:

1. The profile for GGBS is the impacts involved in processing granulated blast furnace slag to produce GGBS. No account has been taken of the impacts of iron-making because the slag evolves irrespective of whether or not it can be used.

2. Includes energy involved in the generation and distribution of electricity.

3. The use of slag for the manufacture of GGBS potentially saves it from having to be disposed of to tip.

This may not be a considerable change to the whole project in itself but demonstrates how every choice has its impacts and has the embedded opportunity for further consideration of sustainability. Understandably the change in concrete specification is not always possible due to technical requirements. However, usually changes like this can be made but are not even considered because designers do not have the information at hand during the design stage to compare the outcomes of their choices.

Similarly, when LCA is used as a supporting tool and proper data are available at the design stage, geotechnical engineers can understand the improvements that can be made by revising the choice of main materials included in the project, such as cement, aggregates and steel. Therefore, material analysis can help designers to better understand their choices and focus their efforts and budgets in reducing impacts where sustainability gains can be made in accordance with technical specifications.

Thus, a good option for further improving the natural resources indicators is to perform LCA on all the main resources used on the project. With these assessments at hand designers could understand better the consumption of the project and where any reduction or substitutions could be made, such as embedment of more recycled materials. However, this could be time consuming and costly due to the complexity of the LCA process. Without LCA analysis, designers need to consider material options using simple assessments such as carbon calculators. However it should always be remembered that this is part of the bigger sustainability assessment process.

Water discharge and water pollution: Water management represents important environmental, economic and social risks for this project: environmental risks, due to the possibility of water pollution of rivers and canals; economic risks, due to cost of dewatering, treatment and discharge of water; social risks, due to the possibility of contaminating drinking water during the excavation and also the risk of soil related problems occurring during dewatering process.

Geotechnical designers will be fully aware of the soil related risks and be completely prepared to deal with this issue. However, the other risks need to be considered with the same attention because dewatering, water discharge and water pollution are all issues that can be improved by design decisions above and beyond legal environmental requirements.

Initially engineers need to consider the best tunneling route and try to avoid the main aquifers as much as possible. After considering the best routes to avoid major water management problems (such as passing through a source protection zone, requiring monitoring to be agreed with the Environmental Agency) consideration also needs to be given to water recycling and water discharge (if dewatering is necessary). In this project, dewatering is not avoidable, therefore to improve sustainability reducing the risk of water pollution it is important to consider further the design route and plan ahead for effective water collection, water recycling, and water treatment from within the design stage. This needs to be done in agreement with the contractor and once more there is opportunity for the designer to influence the contractor in improving the sustainability of the project.

Reusing water from the dewatering process can substantially reduce the need for fresh water during construction, thus both improving natural resource efficiency and reducing waste water.

Also, to reduce the risks of water pollution throughout the construction of the tunnel, designers can influence the specifications of non-toxic tunneling materials to be used during construction (such as biodegradable and non-toxic foaming agents).

Transport: Most of the design decisions have an effect on the transport outcomes of the project. In tunneling projects, main decisions such as pre-fabricating concrete rings rather than concrete spraying the tunnel will considerably change logistics, the transport of materials and the time and equipment needed on site. Moreover, once the main decisions are made, such as to pre-fabricate concrete rings, other decisions, such as deciding the dimensions of the rings sections and the number of the sections needed to complete a ring, will also influence transport determining whether the rings can be carried by smaller trucks, trains or barges. This will influence traffic, air pollution and nuisance to neighbourhood. In this project it also can influence price and programme because deliveries of larger trucks are restricted in Central London.

In the same manner all the other material and equipment decisions will influence the transport and logistics decisions and need to be thought through at the design stage to ensure maximum efficiency and sustainable outcomes.

Thus, to improve transport, design decisions need to be revised with logistics in mind. As an example, for this project, the main transport gains would be to transport the concrete segments via alternative transport methods such as train or barges. This one decision would reduce fuel consumption, CO_2 emissions and reduce traffic to the site routes. To allow this, designers must design the concrete rings in a modular way to facilitate transport.

Health and wellbeing: Health and wellbeing of employees and stakeholders, in tunneling projects, heavily depends on the construction processes and methods chosen by designers. Designers can influence these processes by specifying safe materials and requiring modern equipment, reducing air pollution, dust, noise and vibration on site. Also, the design of temporary works such as hoarding and lighting can help to reduce noise, dust and light effects on the community and external stakeholders. Design for safety will also improve health and wellbeing. Moreover, by improving transport systems, designers can reduce air pollution and traffic improving health and wellbeing of employees and stakeholders simultaneously.

Stakeholder satisfaction: Considering that a more sustainable approach is taken, the indicators above have been reviewed using GeoSPeAR and design improved wherever possible. Therefore stakeholder’s satisfaction was also improved. This is because as mentioned before this indicator is linked to other aspects of the project such as noise and transport and it will reflect performance in the sustainability of these aspects.

Pollution: Because pollution is an overarching theme it can be assessed and improved throughout many indicators. Thus by reducing CO_2 emissions from concrete, reducing risk of water pollution, reducing waste water, reducing air pollution by using alternative transport for materials and avoiding the use of hazardous materials on site as much as possible, designers have already improved the pollution footprint of the project. This shows how collective improvements can be made and the cumulative effects on the sustainability of the project.

Therefore, given that all these observations were considered and approved by the client and contractors the design option would have been substantially improved. To demonstrate graphically the overall improvements that could have been made on the project by reviewing the design decisions a second 'GeoSPeAR' assessment was undertaken (Step 6) (see Figure 8.10 and Figure 8.11).

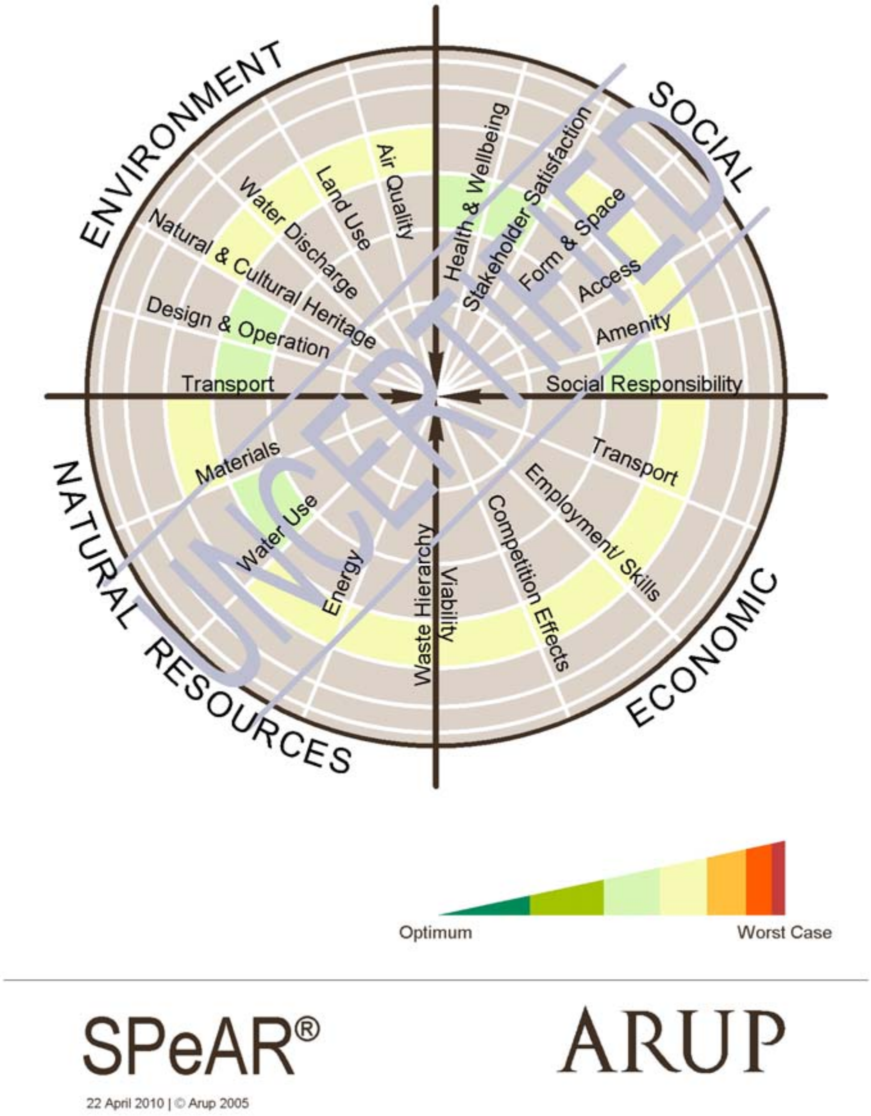


Figure 8.10: 'GeoSPeAR' assessments for Case Study 2: Scenarios 2 – improved geotechnical design

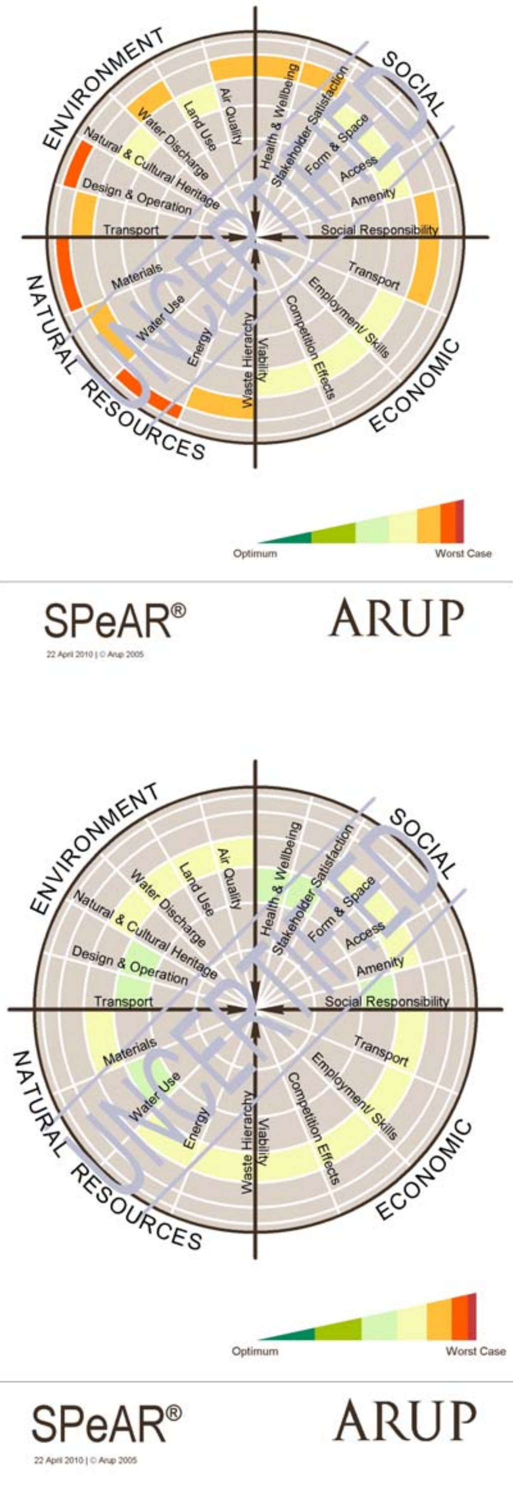


Figure 8.11: Comparison between the two assessments

Comparing both diagrams (Step 7) it can be seen that the revised design (Figure 8.11) shows an overall improvement in the sustainability of the project, especially on the indicators discussed and enhanced above. This shows how the sustainability of the project can be improved at the preliminary design stage without main changes to the design, by design optimisation focused on sustainability aided by 'GeoSPeAR'.

Design optimisation supported by sustainability assessment is by no means a trivial task and can take considerable time and resources to perform. However, it is also a powerful approach which can help the design team to identify the most sustainable design solutions out of a number of feasible design options (Azapagic *et al.,* 2008). Thus, to make decisions in a sustainability perspective, there is a need to move towards sustainable assessment of geotechnical projects.

8.2.4: Improving construction decisions

Designers are not always fully responsible for all the construction decisions. However, by using the 'GeoSPeAR' methodology geotechnical engineers can understand where the construction problems may arise and influence contractors and clients in order further to improve the sustainability throughout the project.

As an example of how clients and contractors can improve the outcomes of the project reducing impacts, one decision that can change several indicators will now be examined. During the construction phase, the C300 phase of Crossrail will use (directly) 61,000,000 KWH during the excavation, production of concrete segments and construction of the tunnel. This was estimated by designers and quantity surveyors in order to calculate costs of energy consumption during the project. These electricity figures are unlikely to be reduced due to the TBM's is high energy consumption and the processes by which the segments need to be produced. However, the CO_2 production and the fossil fuel consumption can be reduced by procuring energy from alternative sources (see comparison between different energy generating technologies on Table 8.6).

Table 8.6: Total lifetime releases of CO_2 from electricity generating technologies. (Lightbucket, 2010)

	Coal	Gas	Solar PV	Nuclear	Wind	Hydro
	kg CO2/MWeh					
ExternE	815	362	53	20	7	-
UK SDC	891	356	16	-	-	-
Wisconsin	974	469	39	15	14	-
CRIEPI, Japan	990	653	59	21	37	18
Paul Scherrer Inst.	949	485	79	8	14	3
UK Energy Review	755	385	-	11-22	11-37	-
IAEA	968	440	100	9 - 21	9 -36	4 – 23
Vattenfall AB	980	450	50	6	6	3
British Energy	900	400	-	5	-	-

As it can be seen from Table 8.6, by procuring electricity generated by alternative technologies such as wind power and nuclear power, the project can reduce emissions considerably. Understandably, electricity procurement is a client and contractor decision, rather than a design only decision. In this way, designers can only explain to clients and contractors the advantages of reviewing electricity sourcing and the effects that this will have on the outcome of the project.

More importantly, understanding hidden effects of procurement choices designers, client and contractors can discuss better solutions for reducing not just the carbon footprint of the project but also other hidden effects of the project such as air quality and natural resource consumption.

8.2.5: Cost implications

The costs implied in this process of improving design and sustainability can be as little or large as the client would allow. The 'GeoSPeAR' assessment can be done as a simple exercise to understand the weaknesses of a project and the decision further to develop LCA balances and change the design option to be more sustainable would depend on budget and client specification.

For this specific tunneling project to be improved from the first to the second design some investment would be needed in design time (to revise the project), SimaPro license and personnel to generate the LCA balances. However, this would not be significant to this project budget due to its size. Some of the actual improvements on the project such as buying a more sustainable concrete mix and switching to a better electricity tariff would have a more significant reducing impact on the initial budget. However with the Carbon Reduction Commitment starting to charge companies in advance for electricity and fuel consumption from 2011 this change in specification could actually become a significant saving for the project. The price of a tonne of carbon is fixed at £12 for the introductory phase in 2011, however for the second phase price estimates range from £16 - £35 per tone (EA, 2010).

Other improvements such as using river barges for transporting the concrete segments to site would be considerably more expensive than using trucks and this would not be offset in any way. Thus to make such improvements the client would have to be willing to pay for the improvement in sustainability.

However, by understanding what is implied by the extra costs and the savings that can be made, clients can make more informed decisions. Also, by using 'GeoSPeAR' to support the decision making process, the choice between two design options can be based on the sustainability assessment rather than just budget. This can be considerably more informative and helpful to clients, designers and contractors enabling them to focus investments in winning initiatives to improve price and programme whilst also supporting sustainable development at the same time.

8.2.6: Overall sustainability of the project

Even the improved project option (Figure 8.10) does not score very well with a 'GeoSPeAR' assessment, leaving plenty of room for improvement (see Table 8.7). This is because by nature a tunneling project is very resource demanding but also because of the location of this project, which affects stakeholders and transport links resulting in a disturbance to society and environment during construction. Nevertheless it is important to evaluate where opportunities and limits are in order to deliver the most sustainably viable solution.

In this project, the overall social and environmental benefits of the project will be available after completion. This is because the completed project will provide better public transport for Londoners offsetting some of the environmental and social negative impacts during the construction stage. In this manner, although the project does not score greatly in sustainability during construction, the overall sustainability of the project is positive to society allowing the project to move forward with planning authorities and investors. Therefore, it is important to take the bigger picture into account when assessing the gains of a project to society. This can be done by understanding the construction and operational social, environmental and economic costs and benefits.

Table 8.7: Further opportunities for improvement Case Study 2
Design and materials: These indicators could be improved by further investigation of 'cradle to grave' impacts of other key materials such as steel. As with the concrete example, this could expose hidden impacts and support sustainability improvements.
Energy: Although this project is very energy demanding further improvements in energy efficiency could have been made if detailed analyses of embedded energy and carbon of materials were carried out. This would support better decision making at design and procurement stage. However, this can be time and cost consuming since this information is not yet available from most of the supply chain.
Transport: Much improvement was done by switching transport modes to lower carbon transport modes such as trains and barges. However no further investigation was done comparing providers of barges and trains to identify the more energy efficient offers available. The choice of suppliers was considered on price rather than environmental credentials. This could have been improved but once again it would impact on the cost of the project.
Pollution: By improving materials, transport and energy management major improvements could have been done on carbon and emissions footprint, thus changing the pollution outcome of the project. This shows that collective action improves overall sustainability and a carbon critical design can impact in many aspects of a project.

8.3: Micropiles

For the third case study a small foundation project was chosen. In this particular project the designer and contractor observed that the current foundation design was inefficient and did not work properly in poor ground conditions found at some locations, and thus required a rethink on the base design.

With this in mind, geotechnical engineers revised the design solution. However the improvements were decided without support from 'GeoSPeAR' or any sustainable assessment system to aid the decision making process.

Therefore, to compare both designs and understand improvements, this case study will assess the sustainability of each design option using the 'GeoSPeAR' methodology.

8.3.1: Overview of the projects

The full project involves the installation of fixed telecommunication network (FTN) cables alongside the track with Global System for Mobile Communications Railway (GSM-R) base stations built approximately every 2km to provide wireless data transmission.

Once complete the FTN will carry all:

- GSM-R base station to base station control signals
- Electrification Controls
- Signalling Bearer Circuits
- Operational and Business Telephones
- Existing Radio Systems

The project works comprise cabling route works and GSM-R base station build. The cabling route works involve the survey and refurbishment of existing concrete cable ducts and the design, installation, jointing, termination and testing of copper and fibre cables. The GSM-R works involve the survey, design and construction of wireless base station sites including concrete bases, mast erection and cabin installation.

Between the start of the contract, the works carried out include:

- 1200km of route works cabling
- 380 GSM-R base station designs
- 350 GSM-R base stations constructed

For this case study the assessment will look only into the design of the concrete base for the wireless base station. Traditionally, large reinforced mass concrete bases were used as foundations for this kind of project. However, the contractor considered this traditional approach inefficiency in poor ground conditions thus required a rethink of the base at some locations, which resulted in a piled solution.

Initially, the client favored a piled solution and an alternative was to use a CFA pile solution. However, with this method 92% of the pile capacity was used to support the pile cap and the remaining 8% supported the steel GSM-R tower - a very inefficient solution. Additionally, access routes for many of the isolated site locations proved to be difficult. This caused problems both with the removal of excavated material and delivery of ready mixed concrete.

As a result of these problems, the designer and contractor developed a “micro pile” solution to support a significantly smaller concrete mast base where ground conditions permitted. This negated the need for a mass concrete base (see Figure 8.12) by using mini piles to support a concrete cruciform (see Figure 8.13) that in turn supports the GSM-R tower.

Figure 8.12: Typical mass concrete base

Figure 8.13: Micropile option - cruciform base and tower

Understanding that the design could be improved even further the client, designer and contractor worked together on the development of an alternative modular design for the GSM-R base station reducing further the use of natural resources and the time for construction on site. Also, by using a modular build with components prefabricated off site, the 'Rapid Deployment Site' (RDS) solution reduces the cost of construction and the time on site to as little as 2 days. Therefore the final solution uses precast concrete support blocks plus steel grillage base that in turn support the tower and cabin.

Main changes in the micropiles design were (see Table 8.8):

- Produces less excavated material generated in both the pile and base construction
- The smaller volume of excavated material can be spread on site and not sent to landfill saving an average of $70m^3$ per site going to landfill ($120 \times 70m^3 = 8400m^3$ total saving to landfill) which in turn has direct cost savings.
- Less concrete used in the base itself and the piles saving an average of $60m^3$ per site ($120 \times 60m^3 = 7200m^3$ total concrete saving)

Table 8.8: Comparison between material consumption of pile options

	Mass RC base	CFA pile	Micropile	Micropile saving
Excavation Base	80 m^3	45 m^3	8.0 m^3	
Excavation Piles	Zero	15 m^3	0.5 m^3	
Excavation Total off site	80 m^3	60 m^3	Zero	60-80 m^3 Per site
Concrete Base	80 m^3	45 m^3	8.0 m^3	
Concrete Piles	Zero	15 m^3	Cement Grout (0.4 w/c ratio)	
Concrete Total	80 m^3	60 m^3	8.5 m^3	50-70 m^3 Per site

This micropile option was trialled both in a yard and out on site before the design was rolled out nationally to all the other contractors working these types of projects.

To compare both options and understand where sustainability could be improved even further two 'GeoSPeAR' assessments were undertaken considering the different designs. Again, the methodology of assessments adopted for both scenarios was the 'GeoSPeAR' method discussed in Chapter 7.

The first assessment considered the typical mass concrete base design solution, designed with a traditional approach and no real consideration of either environmental or sustainable issues. The second assessment considered the micropile solution, designed to reduce problems in locations with poor ground conditions and to improve efficiency of materials.

For both assessments the boundaries (Step 2) were considered to be the same. The geographical boundary was assumed to be the site within one mile (given the small scale of the each project). For social aspects, the boundaries included the local neighbourhood around the sites (within one mile). The design and construction performance was compared to normal practice within the business sector in the UK, with supply chain analysed into the first layer. Both scenarios were assessed using real data from completed projects.

8.3.2: First assessment

The first assessment intended to understand the outcomes of the traditional foundation solution in order to provide data for comparison between both designs.

Thus, Step 1 of the 'GeoSPeAR' methodology was not followed because designers were not briefed on sustainability values before the design process. Also, 'GeoSPeAR' (or a similar system) was not used to support designer's decision making process.

The boundaries (Step 2) and geographical and social boundaries were mentioned above. The data collection (Step 2) was done with help from the designer and contractor. The assessment (Step 3) was done using 'GeoSPeAR' accordingly to the 'GeoSPeAR' assessment model (Chapter 7 – 7.2.3).

8.3.3: Assessment process

1. Understanding the issues

To obtain a comprehensive understanding of the project the designer and contractor was interviewed.

2. Identify stakeholders

All relevant stakeholders, internally and externally, were identified with help of designer and contractor.

3. Indicator review

The core indicators were reviewed in the same way as in the first case study and for each indicator a best and worst scenario were identified prior to the assessment. The best-case scenario was based on encouraging actions that are beyond current environmental, social and economic best practice. Complying with legislation was not considered the best case as this is something that must be done to comply with the law. Thus complying with legislation was assessed as 0, because projects should be aiming to do better than the basic requirements. Once specified, these were also used as project specific objectives for the three assessments. Best practical environmental options and other best practices were assessed as +2 or +1, (not +3), according to the SPeAR assessment methodology (Arup, 2007).

4. Data collation

As mentioned above data were collected from designer and contractor.

5. Workshops

This step of the methodology was not applicable to this case study.

6. Undertake appraisal

Once all the data were collected an initial appraisal was undertaken. Results are shown on the diagram below (Figure 8.14).

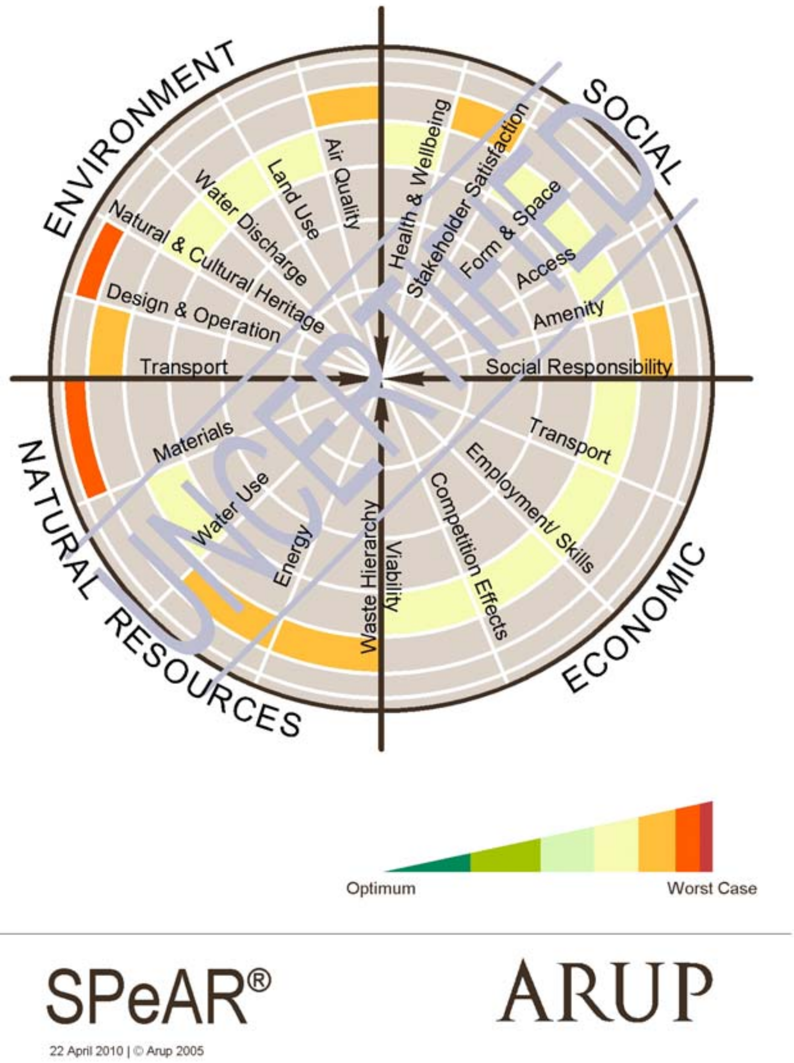


Figure 8.14: 'GeoSPeAR' assessments for case study 3: Scenarios 1 – Typical mass concrete base solution

Figure 8.14 shows the first scenario has considerable room for improvement (Step 4). Particularly, this assessment shows two areas in most need of improvement, design and materials. Also, it shows good opportunities to reduce impacts in air quality, transport, energy, waste hierarchy, social responsibility and stakeholder satisfaction.

The diagram (Figure 8.14) also highlights that not one indicator scored particularly well achieving more than 0 (yellow). This was because on this traditional solution, basic requirements and legislation were respected but no best practice was used to take the project above and beyond compliance with current practices.

Table 8.9: Opportunities for improvement Case Study 3 – Assessment 1
Environment: On the environment quadrant all the indicators could be revised. The current low scores show that this traditional design has considerable room for improvement and probably has not been revised / updated with sustainability as a main value.
Natural resources: Again the lower score in all the indicators under this quadrant show opportunity to improve in materials, water, energy and waste management.
Economic: Economically the design option is viable but does not outperform in any aspect. This shows room for improvement.
Social: The low score in all the indicators shows again lack of innovation, efficiency and good management. Stakeholder satisfaction highlights the overall room for improvement on this quadrant.

8.3.4: Second assessment

The second assessment examined the micropile solution. This assessment intended to highlight the improvements made on the project from design change, and also to explore the opportunities available for further improvements in sustainability. Thus, the assessment followed the same process as the first assessment.

Again, during the design stage, Step 1 of the ‘GeoSPeAR’ methodology was not followed because designers were not briefed on sustainability values before the beginning of design. Also ‘GeoSPeAR’ (or a similar system) was not used to support designer’s decision making process. In this scenario designers were briefed to solve the issues with poor soil conditions and also to improve efficiency of materials. Steps 2 and 3 followed the example above (see Section 8.3.3). The results of this second assessment can be seen in the diagram below (Figure 8.15).

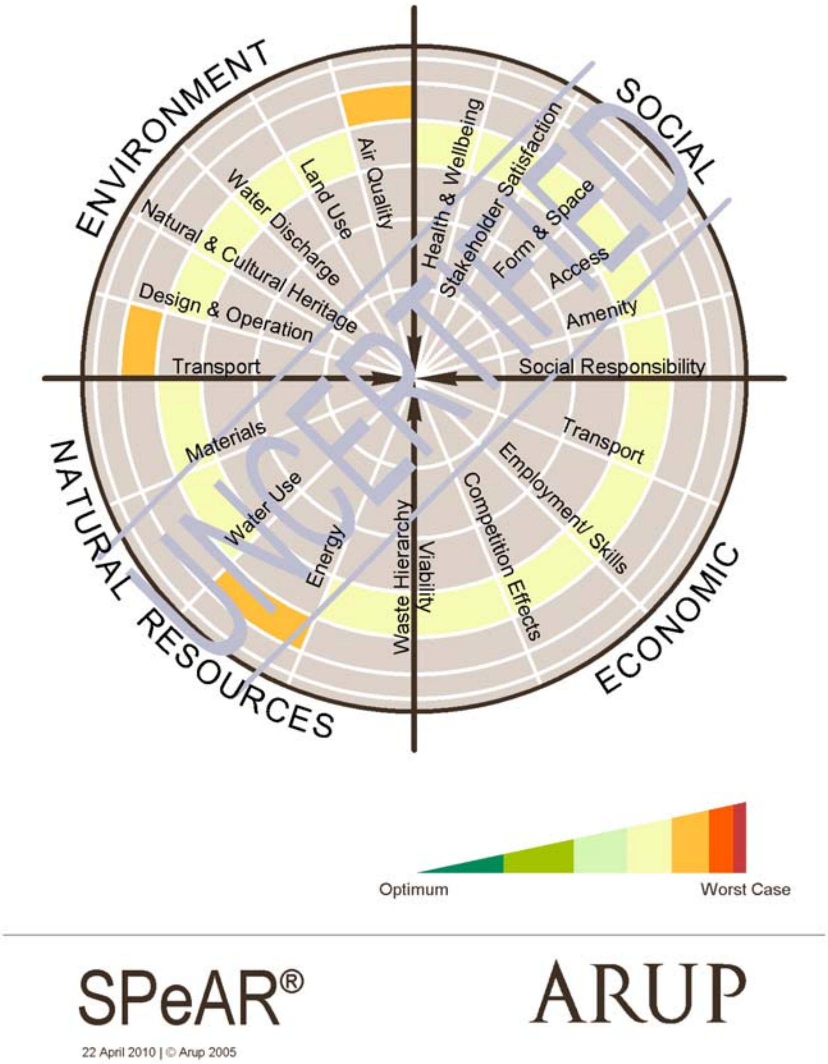


Figure 8.15: 'GeoSPeAR' assessments for case study 3: Scenarios 2 – Micropile solution

Figure 8.15 shows the 'GeoSPeAR' diagram for the micropile design has several improvements. Main changes that can be seen are the design and natural resources indicators (materials, water, energy, waste) due to the focus of the designers in improving efficiency of the foundation layout.

Such improvements show that designers can innovate and review concepts when challenged to improve projects. Moreover, it shows that improvements in design efficiency resulted in improvements in other areas of sustainability as well. In this case these improvements also generated improvements in the construction process, such as:

- The use of a mini piling rig, which is easier to man handle, needs less working room and is quieter on site;
- Only one machine is required to excavate the site and construct the piles;
- Less time on site, less time working close to the railway hence added safety benefits;
- Less disturbance to the surrounding environment and nearby residents;
- Less disruption and damage to restricted access routes often along farm tracks or country roads;
- Less working space required so reducing the need to remove trees and bushes on site.

These benefits to the construction process have also helped further to improve other indicators of sustainability such as air quality, noise, viability, affordability and competition effects.

Therefore it can be observed that by enhancing design decisions at early stages, geotechnical engineers can improve many areas of a project making the project safer, faster, economic, more environmentally friendly and socially improved.

However, in this specific case, because designers were particularly interested in reducing material consumption rather overall sustainability, the second diagram shows that there is still considerable room for improvement in the sustainability of the project (Step 4). Nevertheless, it can be clearly seen the direct results of the design improvements.

This exposes the opportunities that designers have to improve overall sustainability by challenging traditional design models. Also it shows the importance of understanding the sustainability as a whole in order to improve projects evenly in social, economic and environmental aspects.

Table 8.10: Opportunities for improvement Case Study 3 - Assessment 2
Environment: As can be seen on Figure 8.15, improvements were made on the environment quadrant manly due to the reduction of materials use. However improvements could still be made by challenging designers at the beginning of the design stage to further assess opportunities for improvements on sustainability.
Natural resources: Natural resources management could have been further improved by analysing 'cradle to grave' impacts of materials. Also recycled aggregates could have been embedded to the concrete to reduce energy usage and carbon footprint.
Economic: No major change was achieved on this quadrant although the more efficient option was more affordable and this could become more sellable, possibly generating more business. However to further improve competition effects the design would need to be improved to be more sustainable and thus 'sold' as a 'green solution'.
Social: Improvements were made in this quadrant by reducing hours of work, machinery needed and working space. However, further improvements could have been made by the specification of materials coming from suppliers fully certified by environmental and social standards such and ISO 140001, OHSAS 18001, BES 6001.

8.3.5: Improving design further

This case study shows that designers can improve geotechnical projects towards sustainability by rethinking traditional solutions. However, without a system to highlight opportunities in sustainability and direct efforts, designers can change a project with just one or two indicators in mind, such as materials efficiency or CO_2 emissions, and miss many other opportunities to improve the sustainability of the project as a whole.

In this case, further improvements (Step 5) could have been achieved by using 'GeoSPeAR' to understand where the opportunities were. Additionally, geotechnical engineers could have investigated where the hidden impacts of the project were by using supporting tools such as life cycle analysis. Steps 6 and 7 were not followed in this case study because the main objective of this example was to compare two different design options rather than to continuously improve one design solution.

8.3.6: Using LCA to support decision making

LCA can be used to expose 'cradle to grave' outcomes of key project decisions (Step 5). LCA studies allow deeper insight into environmental impacts of products and processes because embedded into the LCA measurements are associated implications such as resource depletion and greenhouse gases. The main advantage of LCA is that it is a well established, standardised methodology where potential impacts are aggregated and quantified (Chau *et al.*, 2008).

As an example of this approach, an LCA study was performed using SimaPro software to expose embodied energy of concrete use of both design options assessed below (see Figure 8.16 and Figure 8.17).

This analysis exposes the layers of embedded energy consumed during concrete production, allowing designers to better understand 'cradle to grave' impacts and the carbon footprint of concrete consumption. Such analysis can be made to every material used in a project supporting decision making process. Moreover the analysis highlights were improvements can be more effective.

In this specific case, by changing the design and reducing the concrete consumption, a reduction in CO_2 production form 354 kg CO_2 to 3.14 kg CO_2 occurs. This, together with reduction in transport of the concrete to site, will result in further reductions on environmental impacts of the design.

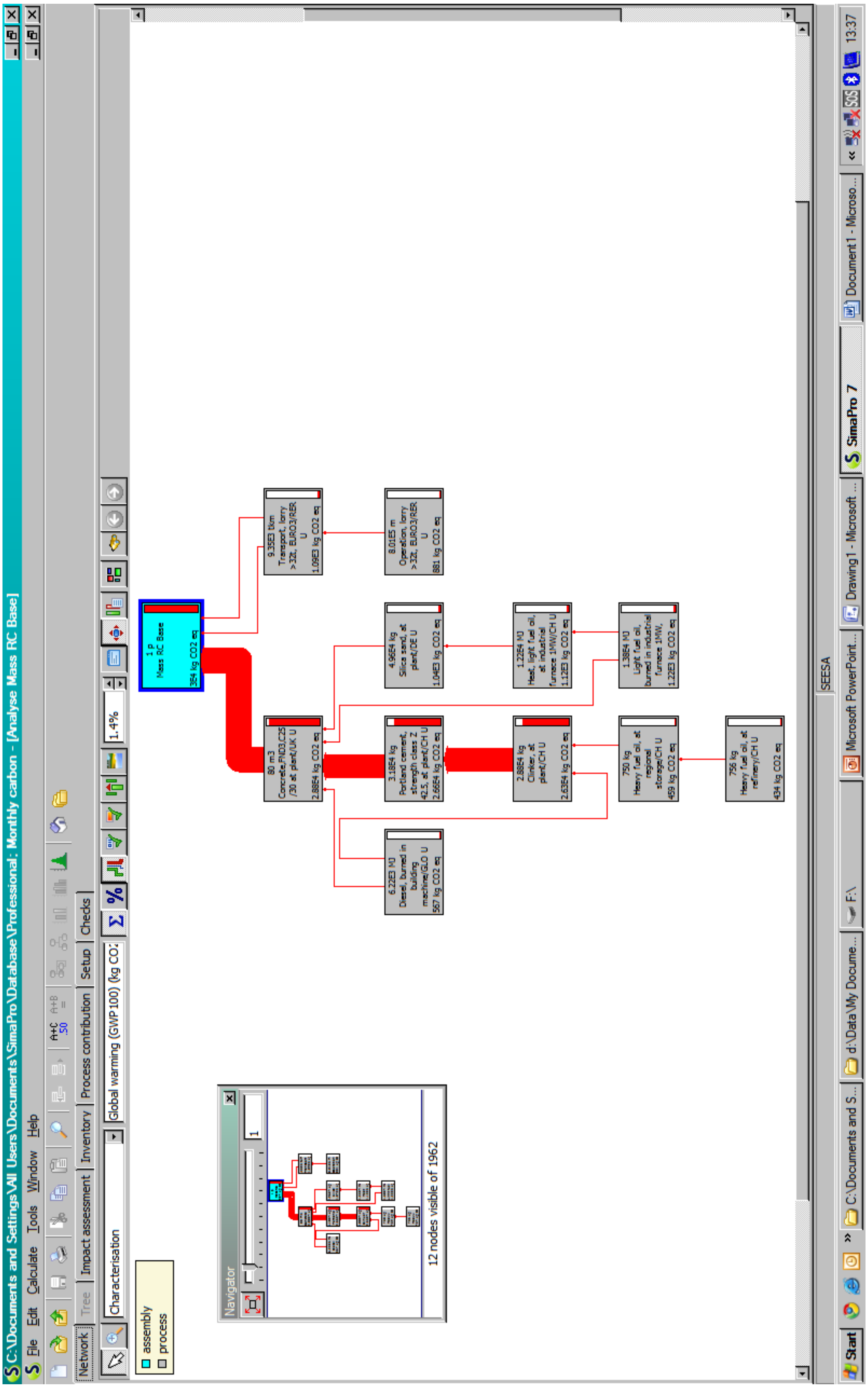


Figure 8.16: LCA assessment of embedded energy consumption for mass RC base design.

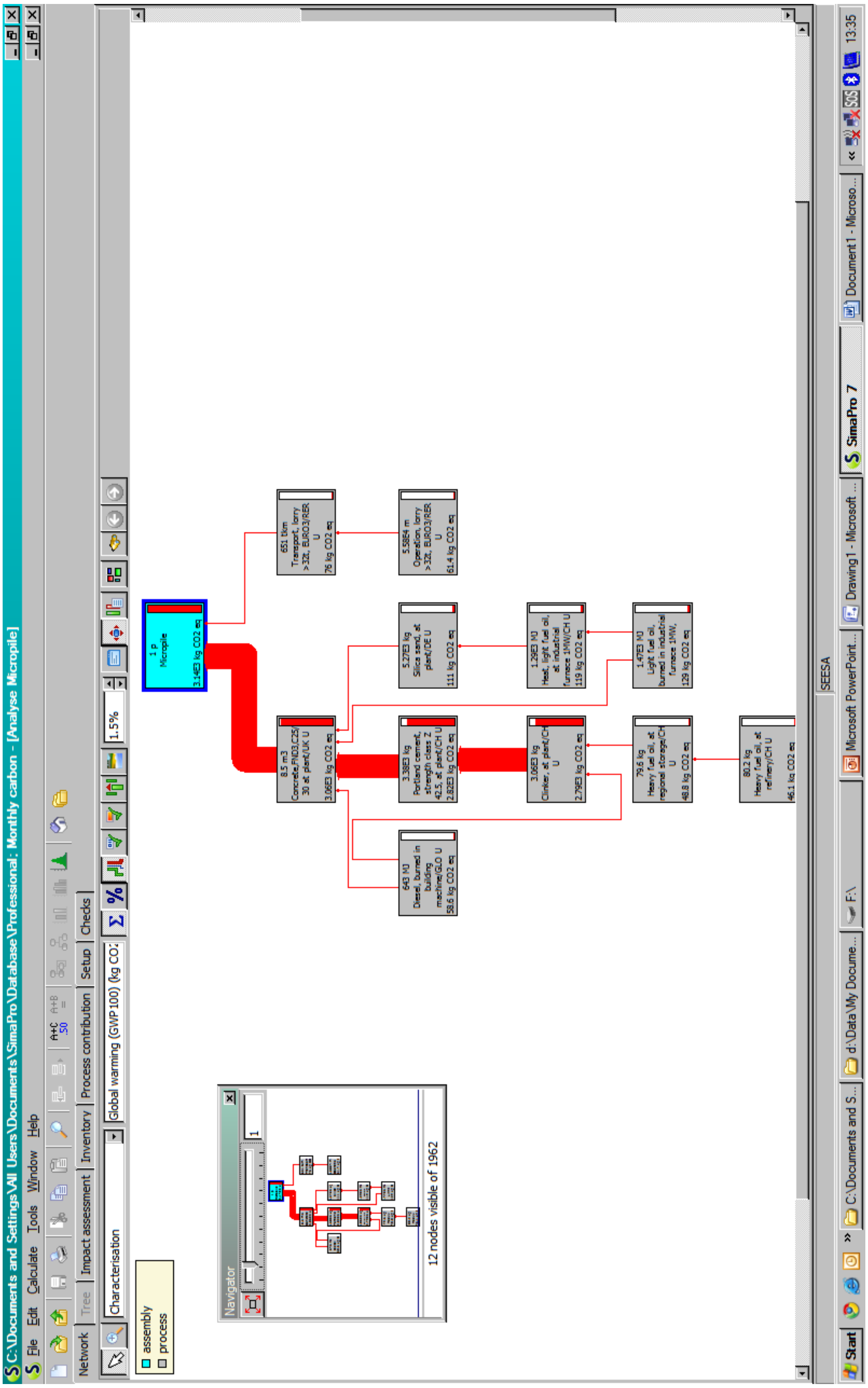


Figure 8.17: LCA assessment of embedded energy consumption for Micropile design.

To quantify and understand better some of the environmental improvements generated by the reduction in concrete on the second design, further LCA analysis was done using the Eco-indicator 99 v2.05 methodology from SimaPro (See Figure 8.18, 8.19 and 8.20). This method uses the damage-oriented approach quantifying impacts in eleven categories: carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/euthrophication, land use, minerals and fossil fuels.

Using SimaPro for the calculation can quantify and visualise impacts of the concrete and transport for each design and also a comparison between both designs.

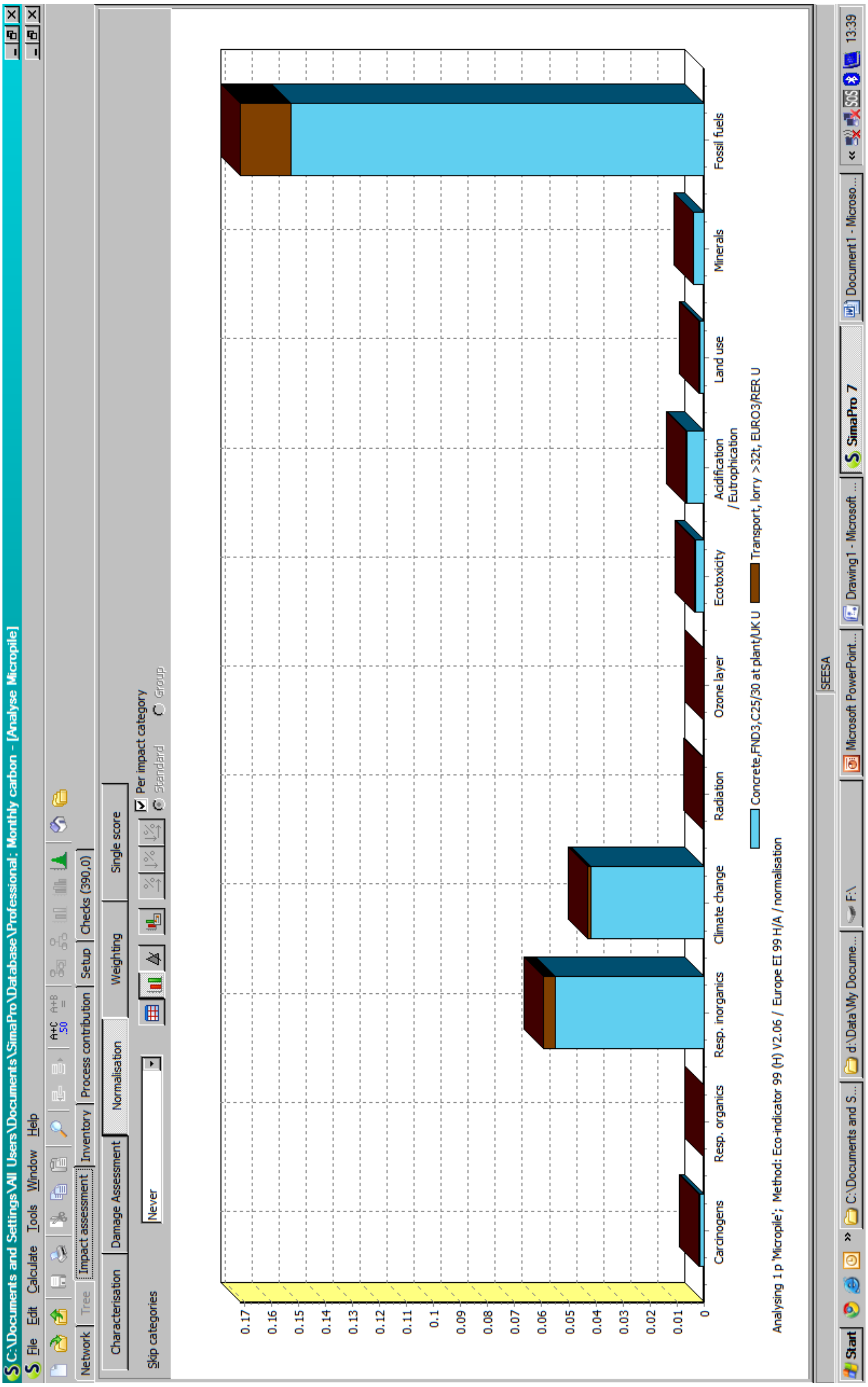


Figure 8.18: LCA assessment using Eco-indicator 99 v2.05 methodology from SimaPro for mass RC base design.

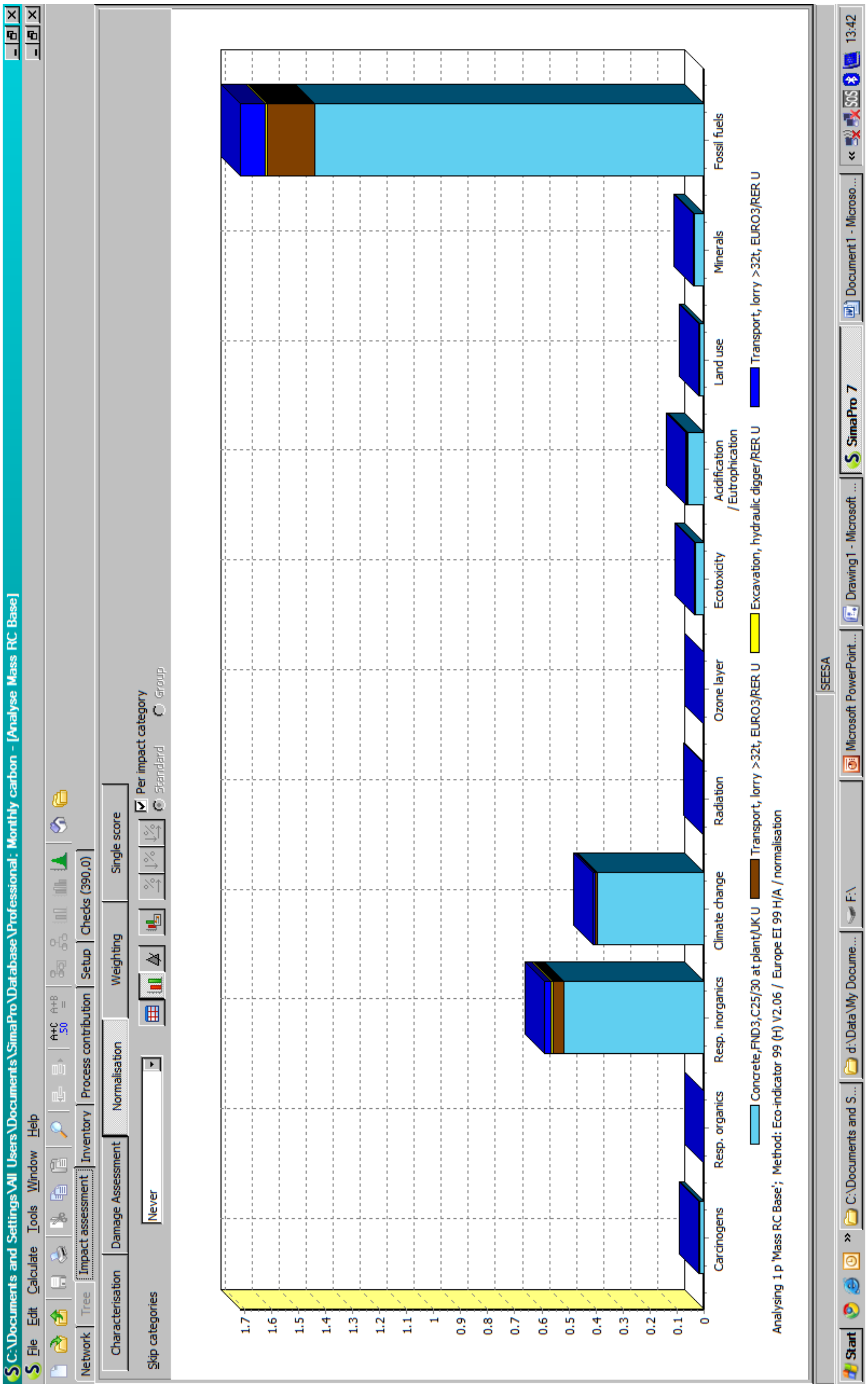


Figure 8.19: LCA assessment using Eco-indicator 99 v2.05 methodology from SimaPro for Micropile design.

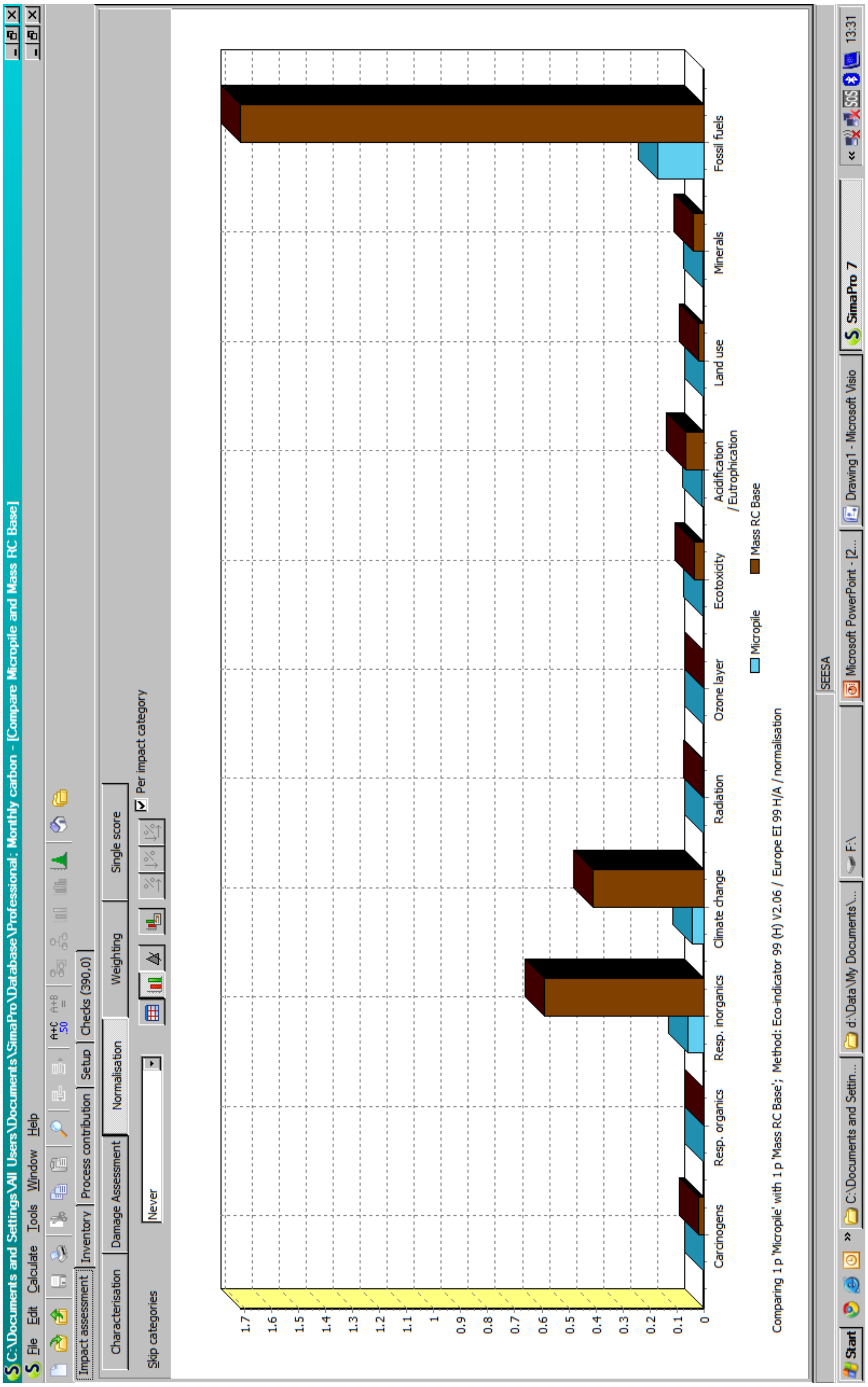


Figure 8.20: LCA comparison between both designs, using Eco-indicator 99 v2.05 methodology from SimaPro.

With this data at hand designers can see that a reduction in material use, in this case concrete, will also reduce other impacts. By understanding potential improvements, geotechnical engineers can investigate alternative materials, embedment of recycled materials and also alternative construction processes.

By using LCA to visualise and understand hidden impacts, geotechnical engineers can attempt to deliver quantified predictions of impacts to support ‘GeoSPeAR’ assessments, improve design further, and evaluate sustainability performance when comparing different design options or an innovative approach to traditional solutions (Keeler and Burke, 2009).

8.3.7: Considerations

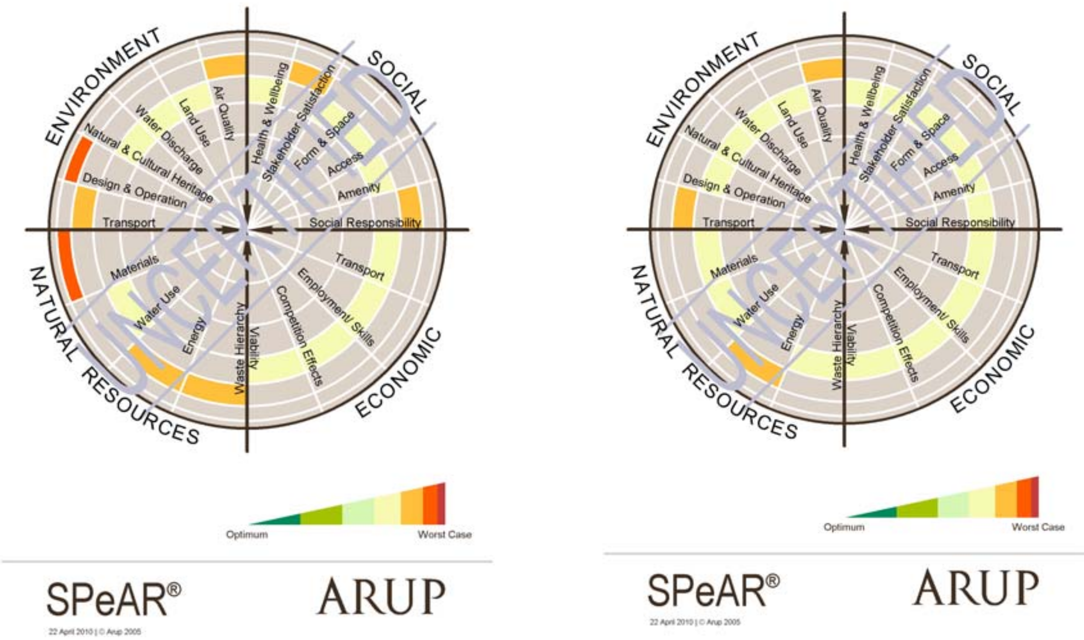


Figure 8.21: Case study 3 - First and second assessments

In this case study, a decision was taken by the geotechnical designers to minimise resource consumption and improve geotechnical design. This decision motivated engineers to improve the design, and the design changes improved the overall sustainability of the project, as can be seen by comparing both ‘GeoSPeAR’ diagrams (see Figure 21).

Although the overall improvements in this case were not generated by a main focus on sustainability this shows the opportunity that designers have at hand and the importance of focusing in the correct direction and values. This also shows that early decisions have the power to change the outcomes of a project considerably, resulting in significant benefits.

Further improvements could have been made if designers were challenged to address other aspects of sustainability as well as efficiency (see table 8.9). With the help of ‘GeoSPeAR’ assessment and LCA analysis, opportunities could be exposed and efforts directed to reduce impacts and enhance benefits. Moreover by using these tools geotechnical engineers could understand the interactions and connections between design and construction processes and improve construction outcomes as well.

Therefore, by briefing designers at the beginning of the decision making process about sustainability values and how to assess sustainability using ‘GeoSPeAR’, sustainability could be embedded into the design from the early stages. This would provide additional means to help geotechnical engineers to explore opportunities, identify priorities, monitor progress and quantify the value delivered through sustainable practices.

CHAPTER 9: Conclusions

9.1: Supporting embedment of sustainability into geotechnical projects

Sustainable Development (SD) calls for coordinated action at all levels of society. It embraces the main interdependent and indivisible areas of environmental protection, economic development and social development (Taskforce on Sustainable Construction, 2007).

Through its impact on the built environment and society, construction plays a central role in the drive to promote sustainable growth and development. However, to implement the necessary changes needed to achieve more sustainable construction, all the sectors of the industry need to be equally engaged and committed to mitigating the unwanted effects of construction and embracing opportunities for improvement.

Such consideration places civil engineering, and consequently geotechnical engineering, at the centre of a process that needs to be remodelled in order to deliver more sustainable construction. Moreover, geotechnical engineering – as an important link in the construction chain – has a significant opportunity to contribute to the sustainable construction agenda.

The literature review showed that there is a significant gap in research concerning how to embed sustainable values into geotechnical projects. In particular, how sustainability can be assessed and therefore managed in the geotechnical process. Therefore, this research has concluded that to embed sustainability into geotechnical engineering an assessment framework with a tool containing appropriate indicators was required. After a detailed review of the tools available, it was decided to adapt and modify an existing tool to avoid potential 'tool fatigue' and so avoiding the development of yet another tool which will in most likelihood never be used.. This allowed the benefits of an existing tool to be enhanced while ensuring key developmental work undertaken during its initial inception was retained.

The system considered to be most suitable for adaptation was SPeAR®. This was due to the key benefits that the SPeAR® approach offers, including: flexibility, relative ease and cost effectiveness of assessments, and ease at which a project can be re-evaluated throughout the life of a project. This enables initial changes made to a project to be monitored and adjusted to suit. Alterations were made to indicators, and to the best and worst case limits used in assessments, to enable the development of an evaluation methodology more appropriate for geotechnical engineering. In addition, Life Cycle Analysis (LCA) was incorporated into this new approach, permitting numerical analysis to take place should the design budget and timetable permit. This allows elements of carbon critical design to be utilized as part of the broader sustainability assessment process for geotechnical projects. The new system was called 'GeoSPeAR', for the purpose of this research. The system developed therefore, retains the key benefits of the SPeAR® system, whilst allowing bespoke assessment of key geotechnical indicators to take place.

As part of the research process, three case studies were assessed using the 'GeoSPeAR' methodology in order to show the practical application of the system. Although the three case studies were different in nature, size, value and stage of construction, the assessment process was similar and many similarities could be seen when evaluating the sustainability of the design options. These included the lack of sustainable assessment during the design process, poor natural resources and carbon management, lack of understanding of consequences of design on logistics/transport outcomes and lack of attention to the implications of irresponsible procurement. In one way or another, these common weaknesses were highlighted throughout the three examples, demonstrating that independent of the project, the lack of focus on sustainability as a whole can result in consistently unsustainable outcomes.

Moreover the three case studies have clearly displayed that comprehensive interaction between client, designers and contractors is crucial from stage one of the design if sustainable gains are to be maximised.

In particular, these case studies highlighted how there has been a tendency with geotechnical projects to focus on improving a few specific indicators of sustainability such as biodiversity and material efficiency, whilst designers missed the more holistic view and so are not achieving the full sustainability potential possible. The research presented in this thesis has shown that without a robust framework and broad set of sustainability indicators encompassing all three pillars of sustainability, geotechnical designers have failed to identify many unsustainable practices and chances for improvements towards sustainability. With the help of the 'GeoSPeAR' methodology the projects reviewed highlighted the opportunities for improvements and how improvements in the embedment of sustainability were possible. By understanding precisely where the main opportunities for improvement are designs can be enhanced by taking into consideration the full social, economic and environmental implications.

In observing the final outcomes of the case studies it can be seen that 'GeoSPeAR' has the real potential to fulfill its main aim of aiding designers in understanding unsustainable decisions and giving direction for embedment of sustainability into geotechnical projects. The framework establishes a clear process for data collection and assessment of design options, guiding geotechnical engineers to recognise where action is needed if sustainability is to be enhanced. Moreover, this can be achieved in a robust, objective and consistent way, whilst maintaining flexibility and monitoring capacities.

In this systematic way 'GeoSPeAR' can truly support geotechnical engineers in embedding sustainability into projects. Therefore, by delivering sustainable geotechnical projects geotechnical engineers can directly contribute to sustainable construction and subsequently sustainable development. However, to support sustainable construction, geotechnical engineers need to take responsibility and action to change the way they currently approach design. This suggests nothing less than a substantial change in current modes of design, starting with a change in decision-making to achieve a sustainable way of living in the future.

By having a suitable framework, with an appropriate tool and associated decision making process, by which sustainability, and therefore sustainable benefits, can be considered, there is scope for reflection and enhancements of sustainable value in geotechnical projects. Thus this enables greater exploitation of desirable outcomes and opportunities to turn current potential sustainability "failures" into positive contributions to future projects.

Additionally it is important to note that while a tool and methodology have been developed to provide a robust sustainability assessment framework, the assessment itself it is only as good as the assessor behind the system. Therefore, geotechnical engineers must understand and embrace sustainability fully in order for the framework to give maximum benefit in embedding sustainability into geotechnical engineering, construction and society.

9.2: Further development

Further development of the ‘GeoSPeAR’ methodology is needed to ensure this approach is suitably robust across all scales (temporal and spatial) of the broad range of geotechnical projects encountered in Civil Engineering. In particular it would be extremely beneficial to test ‘GeoSPeAR’ on live projects from the start of their inception, through to their completion. This would provide the opportunity to fully ‘road test’ the framework and decision support developed and to see in particular how practicing engineers utilise the approach and the assessments made, throughout the life of a project. Further to this, an evaluation of the use of the GeoSPeAR approach on different international projects would allow culturally driven attitudes to be evaluated, so enabling the potential development of a universal approach to assessing the sustainability of geotechnical engineering projects.

Another key driver starting to really impact the civil engineering, and thus is turn the geotechnical, industry is the issue of Carbon Critical Design. Thus is would be extremely useful and informative to utilize the 'GeoSPeAR' approach taking on broad carbon analysis to see how the trade off between carbon focus design and broader sustainability assessments aligns, and to see if there are any conflicts/barriers that a focus on carbon generates for sustainability.

References

Arup (2007) SPeAR Handbook

Abreu D G, Jefferson I, Braithwaite P A and Chapman D N (2008) Why is Sustainability Important in Geotechnical Engineering? Proceedings of session of GeoCongress 2008: Geosustainability and Geohazard Mitigation: 821 -828

Autodesk (2010) Building Information Modelling. See http://usa.autodesk.com/company/building-information-modeling (assessed June, 2010)

Azapagic A, Slobodan P, Roland C (2008) Sustainable Development in Practice: Case studies for engineering and scientists. John Wiley & Sons. ISBN 0-470-85608-4

Babu G L L, Basha B M (2008) Optimum Design of Cantilever Retaining Walls Using Target Reability Approach. Int. G. Geomech Volume 8 (4): 240-252, ASCE

Bardos P (2009) Report of the NICOLE workshop: environmental decision support systems.

Land Contamination & Reclamation, Volume 17(2): 275-314

Bargwanna S (2009) Building a Sustainable Infrastructure Project. SSEE International Conference – Solutions for a Sustainable Planet, Society for Sustainability & Environmental Engineering, Melbourne, Victoria, Australia: 22-24

Bleischwitz R and Hennicke P (2004) Towards a Governance Structure for Sustainable Development. Esri Studies Series on the Environment. Edward Elgar Publishing Ltd ISBN-10: 1843766876

Bossel Hartmut (1999) Indicators for sustainable development: Theory, Method, Applications. International Institute for Sustainable Development (IISD), Canada ISBN 1-895536-13-8

Boyko C T, Cooper R, Davey C L, Wootton A B (2006) Addressing sustainability early in the urban design process. Management of Environmental Quality: An international journal,17 (6): 689-706

Braithwaite P (2007) Improving company performance through sustainability assessment. Proceedings of the Institution of

Civil Engineers, Engineering Sustainability 160(2): 95–103

BRE (2010) See http://www.breeam.org/ (accessed June, 2010)

BRE_2 (2010) Regional Sustainability Checklist for Developers. See http://southeast.sustainability-checklist.co.uk/ (accessed June, 2010)

BRE_3 (2010) ENVEST 2. See http://envest2.bre.co.uk/ (accessed June, 2010)

BRE_4 (2010) Code for sustainable homes.

See http://www.communities.gov.uk/planningandbuilding/buildingregulations/legislation/codesustainable/ (accessed June, 2010)

Brundtland Commission: World Commission on Environment and Development (1987) Our Common Future, Report of the World Commission on Environment and Development. Published as Annex to General Assembly document A/42/427, Development and International Co-operation: Environment August 2, 1987

Butcher A P, Powell J J, Skinner H D (2006) Reuse of Foundations for Urban Sites (RUFUS). Proceeding of International Conference (2006) HIS BRE Press ISBS-10: 1-86081-939-7

Carson R (1962) Silent spring. Houghton Mifflin, ISBN: 9780618249060

CEEQUAL (2008) Scheme Description and Assessment Process Handbook. See http://www.envirolinknorthwest.co.uk/envirolink/Events0.nsf/0/71D63F9B2ED32E848025760B00378E72/$file/CEEQUAL%20Assessment%20Manual%20Version%204%20Process%20Handbook.pdf (accessed June, 2010)

Chau C, Soga K and Nicholson D (2006) Comparison of embodied energy of four different retaining wall systems. Proceedings of International Conference on Reuse of Foundations for Urban Sites. (Butcher AD et al. (eds)). HIS press, London: 277–285

Chau C, Soga K, Nicholson D, O'Riordan N and Inui T (2008) Embodied energy as an environmental indicator for basement wall construction. Proceedings of Geocongress 2008, Geotechnical Special Publication No. 178 ASCE, New Orleans: 867–874

CIB (1999) CIB Agenda 21 for sustainable construction: why, how and what. Building Research & Information, Volume 27 (6): 347 – 353

CIOB (2001) Sustainability and Construction. See www.ciob.org.uk/filegrab/sustainability.pdf?ref=74 (assessed June 2010)

CL:AIRE (2010) Contaminated Land: Applications in Real Environments. See http://www.claire.co.uk/about.htm (accessed June, 2010)

Clarke B G (2010) Carbon Critical Design. Proceedings of the Institution of Civil Engineers, Geotechnical Engineering 163 (2): 57-59

Cole M, Lynch D (2010) London 2012: Brown to Green. New Civil Engineering, 01.07.2010

COP15 (2010) UN Climate Change Conference 2009. See http://www.denmark.dk/en/menu/Climate-Energy/COP15-Copenhagen-2009/cop15.htm (accessed June, 2010)

World Summit for Social Development Copenhagen (1995) See http://www.un.org/esa/socdev/wssd/ (assessed June, 2010)

Dahl A L (2008) Science and Religion in the Climate Change Debate: Case Study of the Baha'i Community. Ethics and Climate Change Conference: Scenarios for Justice and Sustainability, Padova, Italy, 23-25 October 2008

DEFRA (1999) A Better Quality of Life. See http://www.berr.gov.uk/files/file13547.pdf (accessed June, 2010)

DEFRA (2004) Achieving a Better Quality of Life. See http://www.defra.gov.uk/sustainable/government/ (accessed June, 2010)

DEFRA (2007) Sustainable development action plan.

See http://www.communities.gov.uk/publications/corporate/sustainabledevelopment2007-08 (accessed June, 2010)

DEFRA (2009) See http://www.defra.gov.uk/sustainable/government/publications/index.htm (accessed June, 2010)

DEFRA (2010) Implementing the Climate Change Act 2008 (2010) See http://www.defra.gov.uk/environment/climate/legislation/ (accessed June, 2010)

De Simone L D, Popoff F (2000) Eco-efficiency: the business link to sustainable development , Cambridge, MA MTI press

DETR: Department of the Environment, Transport and the Regions: London (2000) Building a Better Quality of Life.

See http://www.berr.gov.uk/files/file13547.pdf

Dickson M (2002) Engineering building for a small planet: towards construction without depletion. The Structural Engineering Magazine, February 2002: 35- 43

Dixon J H, Hall C (2010) Briefing: New geogrid technology for ground stabilization. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 163(2): 65-67

Dixon T (Ed), Raco M (Ed), Catney P (Ed), Lerner D N (Ed) (2007) Sustainable Brownfield Regeneration: Liveable Places from Problem Spaces, Wiley Blackwell.

DTI: Department of Trade and Industry, Partners on Innovation (2002) Ground storage of building heat energy. See http://www.arup.com/_assets/_download/download352.pdf (accessed June, 2010)

DTI: Department of Trade and Industry (2004) Research and Development Relief for Corporation Tax. See http://www.hmrc.gov.uk/ct/forms-rates/claims/randd.htm

DTI: Department of Trade and Industry (2006) Review of Sustainable construction. See http://www.bis.gov.uk/files/file34979.pdf (accessed June, 2010)

E-CORE (2005) Strategy for Construction. See www.eccredi.org/downloads/Summary.pdf (accessed June2010)

Edil T B (2009) Geotechnics of sustainable construction 2nd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering, Near East University, Nicosia, North Cyprus

Egan D, Slocombe B C (2010) Demonstrating environmental benefits of ground improvement.

Proceedings of the Institution of Civil Engineers, Geotechnical Engineering 163 (1): 63 –69

Elghali L, Clift R, Begg KG and McLaren S (2008) Decision support methodology for complex contexts. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 161(1): 7–22

Engel-Yan J, Kennedy C, Saiz S, Pressnail K (2005) Toward sustainable neighbourhoods: the need to consider infrastructure interactions. Canadian Journal of Civil Engineering 32(1): 45–57

Environment Agency (1990) Environmental Protection Act 1990. See http://www.opsi.gov.uk/acts/acts1990/ukpga_19900043_en_1.htm (accessed June, 2010)

Environment Agency (2009) Carbon calculator for construction activities. See http://www.environment-agency.co.uk/business/sectors/37543.aspx

Environment Agency (2010) CRC Energy Efficiency Scheme. http://www.environmentagency.gov.uk/business/topics/pollution/98263.aspx

Farsari Y, Prastacos P (2002) Sustainable Development Indicators: An overview, Foundation for the Research and the Technology Hellas (FORTH), see http://www.iacm.forth.gr/papers/Asteras-English.pdf (accessed June, 2010)

Fenner R A, Ryce T (2007) A comparative analysis of two buildings rating systems Part I: Evaluation. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 161(1): 53–63

Fleming P R, Frost M W, Lambert P J (2006) Sustainable Earthworks Specifications for Transport Infrastructure. Journal of the Transportation Research Board, Volume 1975: 73-80

Flint R W (2004) The sustainable development of water resources. University council on water resources, Water resources up date, Issue 127: 41-51

French S, Geldermann J (2005) The varied contexts of environmental decision problems and their implications for decision support. Environmental Science and Policy, 2005, 8, No X: 378-391

Fricker A (2001) Measuring up to sustainability – Sustainable Futures.

See http://www.metafuture.org/articlesbycolleagues/AlanFricker/Measuring%20up%20to%20Sustainability.htm (accessed June, 2010)

Gervase, B R, (1995) Appreciative Inquiry as an Organization Development Intervention. Organization Development Journal, 13:3, 14-22

Glendinning S, Loveridge F, Starr-Keddle R E, Bransby M F, Hughes P N (2009) Proceedings of the Institution of Civil Engineers, Engineering Sustainability 162 (2): 101 –110

Green Building (2010) Leadership in Energy & Environmental Design See http://www.ukgbc.org/ (accessed June, 2010)

Greenline (2010) Dongtan Eco-city. See http://greenlineblog.com/2007/12/dongtan-eco-city-sustainable/ (accessed June, 2010)

Harbottle MJ, Al-Tabbaa A and Evans CW (2007) Sustainability of land remediation. Part 1: overall analysis. Proceedings of the Institution of Civil Engineers, Geotechnical Engineering 161(2): 75 92

Henriques A (2010) Corporate Impact: Measuring and managing your social footprint. Earthscan ISBN 978-1-84407-653-6

Higgins (2006) embodied CO2 of factory-made cements and combinations.

See http://www.ecocem.ie/downloads/Embodied_CO2_of_Factory-Made_Cements_and_Combinations.pdf?PHPSESSID=f92837e7f4666f83267bebd968e5b481

Highways Agency (2003) Building Better Roads. See www.highways.gov.uk/aboutus/documents/better_roads.pdf (accessed June, 2010)

Hillier RP, Thompson RP, Schroeder F, Baardvik Gand Ha°rvik L (2005) Sustainable Geotechnics. Highways Agency, London.

HM Government (2008) CrossRail Act. See http://www.opsi.gov.uk/acts/acts2008/ukpga_20080018_en_1 (accessed June, 2010)

Holt D G, Jefferson I, Braithwaite PA and Chapman DN (2010) Embedding sustainability into geotechnics. Part A: methodology. Proceedings of the Institution of Civil Engineers, Engineering Sustainability (in press)

Holvikivi J (2007) Learning styles in engineering education: the quest to improve didactic practices. European Journal of Engineering Education, Volume 32 (4) : 401 – 408

HSE (2009) Health and Safety at Work etc Act 1997, see http://www.hse.gov.uk/legislation/hswa.htm (accessed June, 2010)

Hunt D V L, Rogers C D F (2005) Barriers to sustainable infrastructure in urban regeneration. Proceedings of the

Institution of Civil Engineers, Engineering Sustainability 158(2): 67–81

Hunt D V L, Lombardi R D, Jefferson I and Rogers C D F (2008) The development timeline framework: a tool for engendering sustainable use of underground space. Proceedings of Geocongress 2008, Geotechnical Special Publication No. 178. ASCE, New Orleans: 859–866

Hurley L, Ashley R and Mounce S (2008) Addressing practical problems in sustainability assessment frameworks. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 161(1): 23–30

Hyde et al (2006)

Institution of Civil Engineers (2007) Sustainable Development Strategy and Action Plan for Civil Engineering, July 2007

Institution of Civil Engineers (2009) State of the nation low carbon structures. See http://www.ice.org.uk/Information-resources/Document Library/State-of-the-Nation--Low-Carbon-Infrastructure (accessed June, 2010)

IISD (2009) The Sustainable Development Timeline. See http://www.iisd.org/pdf/2009/sd_timeline_2009.pdf (accessed June, 2010)

IPCC (2007) Summary for Policymakers in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press

Jarnehammar A, Green J, Kildsgaard I (2007) Barriers and possibilities for a more energy efficient construction sector, IVL Swedish Environmental Institute. See http://www.secureproject.org/download/18.3d9ff17111f6fef70e9800056617/Barriers+and+possibilities+for+a+more+energy+efficient+construction+sector.pdf (accessed June, 2010)

Jefferis S A (2008) Moving towards sustainability in geotechnical engineering. Proceedings of Geocongress 2008, Geotechnical Special Publication No. 178. ASCE, New Orleans: 844–851

Jefferis S A (2005) Geotechnics in harmony with the global environment: Dream or deliverable? Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering, Osaka, Japan

Jefferson I, Hunt D V L, Birchall C A and Rogers C D F (2007) Sustainability indicators for environmental geotechnics. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 160(2): 57–78

Jefferson I, Gaterell M, Thomas A M and Serridge C J (2010) Emissions assessment related to vibro stone columns. Institution of Civil Engineers, Geotechnical Engineering 156(2): 63–73

Jowitt P W (2004) Sustainability and the formation of the civil engineer. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 157: 79-88

Kapelan Z, Savic D A, Walters G A (2005) Decision-support tools for sustainable urban development. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 158: 135-142

Kastenhofer K, Rammel C (2005) I Obstacles to and potentials of the societal implementation of sustainable development: a comparative analysis of two case studiesnstitute for Ecology and Conservation Biology. University of Vienna, Althanstr. Vienna, Austria. See http://ejournal.nbii.org/archives/vol1iss2/0407-01.kastenhofer.html (accessed June, 2010)

Keeler M, Burke B (2009) Fundamentals of integrated design for sustainable building. John Wiley & Sons, Inc.

ISBN 978-0-470-15293-5

Keijzers G (2004) Business, Government and Sustainable Development. (Routledge Advances in Management and Business Studies)

Kessler D (2008) How sustainable is the fish on your pond? See http://www.huffingtonpost.com/daniel-kessler/how-sustainable-is-the-fi_b_149607.html (accessed June, 2010)

Kiani M, Parry T and Ceney H (2008) Environmental life-cycle assessment of railway track beds. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 161(2): 135–142

Kilsby C G **(2009)** Modelling transient climate change. Part 2: Weather Generator and projected changes. Submitted to Journal of Hydrology. See http://www.ceg.ncl.ac.uk/water/research/publications.htm (accessed June, 2010)

Kornevall C (2008) Energy efficiency in buildings. Megatrends Conference, CIB International Council for Research and Innovation in Building Research, Brazil

Lightbucket (2010) Carbon emissions from electricity generation: the numbers see http://lightbucket.wordpress.com/2008/02/20/carbon-emissions-from-electricity-generation-the-numbers/ (accessed June, 2010)

Lozano R (2006) Envisioning Sustainability Three-Dimensionally. The Centre for Business Relationships, Accountability, Sustainability & Society (BRASS), Cardiff University. See http://www.brass.cf.ac.uk/uploads/WP39LozanoFinal.pdf (accessed June, 2010)

Martin A J (2004) Concrete bridges in sustainable development. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 157(4): 219 –230

Meadows D (1998) Indicators and information systems for sustainable development http://www.sustainer.org/pubs/Indicators&Information.pdf (accessed June, 2010)

Meldrum A, Hare B, Cameron I (2009) Road testing a health and safety worker engagement tool-kit in the construction industry. Engineering, Construction and Architectural Management, 16 (6): 612 – 632

Menzies GF, Turan S and Banfill PFG (2007) Life cycle assessments and embodied energy: a review. Proceedings of the Institution of Civil Engineers, Construction Materials 160(4): 135–143

Mihelcic J R, Paterson K G, Phillips L D (2003) Educating engineers in the sustainable futures model with global perspective. Sustainable Futures Institute, Michigan Technology Institute, for more information: jm41@mtu.edu

Millis S W, Ho A N L, Chan E K K (2008) Instrumentation and real time monitoring of slope movement in Honk Kong. The 12th International conference of International Association for Computer Methods and Advance in Geotechnics (IACMAG), Goa, India

Molina M, Rowland S (1974) See http://nobelprize.org/nobel_prizes/chemistry/laureates/1995/molina-lecture.pdf (accessed June, 2010)

Munda G (2003) Measuring Sustainability: A multi-criterion framework. Environment, Development and Sustainability Journal, 7:117-134 DOI10.1007/s10668-003-4713-0

NICOLE (2010) (Network for Contaminated Land in Europe), see http://www.nicole.org/general/summary.asp (accessed June, 2010)

Osorio, L A R, Lobato, M O, Álvarez C (2005) Debates on sustainable development: towards a holistic view of reality. Environ. Dev. Sust. 7: 501-518

Panteliour H (2008) Review of Embodied Energy in Construction of Geotechnical Highway Structures. See http://www.ha-research.gov.uk/projects/index.php?id=1131 (accessed June, 2010)

Parkin S, Sommer F and Uren S (2003) Sustainable development: understanding the concept and practical challenge. Proceedings of the

Institution of Civil Engineers, Engineering Sustainability 156(1): 19–26

Patel D, Nicholson D, Huybrechts N, Maertens J (2007) The observational approach in geotechnics. See http://www.arup.com/_assets/_download/41A6ACB0-DD6E-06AC-F7C03C57BF321BA5.pdf. (assessed June, 2010)

Pediaditi K, Wehrmeyer W and Chenoweth J (2006) Sustainability evaluation for brownfield redevelopment. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 159(1): 3–10.

Pepper C, Bateson A, Broadhurst M (2007) Sustainable development strategy and action plan for civil engineering, ICE, ACE, CECA, CIRIA

Phear A, Patterson D, Warren C (2003) Sustainable chalk fill transfer from Channel Tunnel Rail Link. Proceedings of the Institution of Civil Engineers, Geotechnical Engineering 156(2): 63–73

Price, A D F, Moobela, C, Mathur, V (2009) Assessing Urban Social Sustainability: Current Capabilities and Opportunities for Future Research, The International Journal of Environmental, Cultural, Economic and Social Sustainability, Vol. 3

Raffield T, Herben M, Billington S, Longhurst P, Pollard S (2006) Coupling hidden flows and waste generation for enhanced materials flow accounting. Centre for Resource Management and Efficiency, Sustainable Systems Department, School of Applied Sciences, Cranfield University, Bedfordshire

RESCUE (2007) Regeneration of European sites in Cites and Urban Environments project. See http://www.eugris.info/displayresource.asp?Cat=web%20links&ResourceID=371 (accessed June, 2010)

Rey-Valette H, Damart S, Roussel S (2007) A multicriteria participation-based methodology for selecting sustainable development indicators: an incentive tool for concerted decision making beyond the diagnosis framework, International Journal of Sustainable Development, 10 (1/2): 122-138

Royal Academy of Engineering (2005) Engineering for sustainable development: guiding principles. See http://www.raeng.org.uk/events/pdf/Engineering_for_Sustainable_Development.pdf (accessed June, 2010)

SEESA: South East Electricity Substation Alliance (2010) Unpublished. For further information contact RobMcCulloch@seesa.co.uk

Serrige C J (2007) Achieving sustainability into vibro stone column techniques. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 158 (4):211 – 222

Simpson B, Tatsuoka F (2008) Geotechnics: the next 60 years. Geotechnique, 58 (5):357-368

Spaulding C, Masse F, LaBrozzi (2008) Ground improvements technologies for a sustainable world.

Proceedings of Geocongress 2008, Geotechnical Special Publication No. 178 ASCE, New Orleans: 891–898

SRSCR (1977) See http://www.scribd.com/doc/8592939/Behaviour-Change-and-Worker-Engagement-Practices-Within-the-Construction-Sector (accessed June, 2010)

Stern N (2006) Stern review on the economics of climate change, HM Treasury, London

Storesund R, Massey J and Kim K (2008) Life cycle impacts for concrete retaining walls vs. bioengineered slopes. Proceedings of Geocongress 2008, Geotechnical Special Publication No. 178 ASCE, New Orleans: 875–882.

Strategic Forum for Construction (2008) Strategy for sustainable construction, HM Government. See www.berr.gov.uk/files/file52843.pdf (accessed June, 2010)

Strategic Forum for Construction (2009) Progress report on the strategy for sustainable construction, HM Government. See www.berr.gov.uk/files/file52843.pdf (accessed June, 2010)

SUBR:IM (2010) Sustainable Urban Brownfield Regeneration: Integrated Management See http://www.subrim.org.uk/ (accessed June, 2010)

SuRF-UK (2010) See http://www.nicole.org/news/downloads/leuven2009/14Key%20Performance%20Ind%20-%20Frank%20Evans.pdf (accessed June2010)

Sustainability Index (2009) See http://www.sustainability-index.com/ (accessed June, 2010)

Sutcliffe L F R, Maier A M, Moultrie J and Clarkson P J (2009) International Conference on Engineering Design, ICED'09 24 - 27 August 2009, Stanford University, Stanford, CA, USA

Taskforce on sustainable construction, 2007 communication supply chain

Tibbs H (1999) Sustainability. Deeper News, Global Business Network January.

Tranter R, Jefferson I, and Ghataora G (2008) The use of recycle aggregate in vibro stone colums – a UK perspective. Proceedings of sessions of GeoCongress 2008: Characterization, Monitoring, and Modeling of GeoSystems (GSP 179) ASCE.

UN (2010) See http://www.un.org/millenniumgoals/pdf/MDG%20Report%202010%20En%20r15%20-low%20res%2020100615%20-.pdf (accessed, June2010)

UNGA (2000) United Nations Millennium Declaration. See http://www.un.org/millennium/ (accessed June, 2010)

Von Schomberg R. (2002) The objective of sustainable development: are we any closer? Foresight, Working Papers Series No. 1, available at: ftp://ftp.cordis.europa.eu/pub/foresight/docs/fores_wp_0210.pdf (accessed June 2010)

WBCSD (2008) Energy Efficiency in Buildings see http://www.wbcsd.org/DocRoot/1QaHhV1bw56la9U0Bgrt/EEB-Facts-and-trends.pdf (assessed May, 2011)

Walton J S, El-Haram M, Castillo N H (2005) Integrated assessment of urban sustainability. Proceedings of the Institution of Civil Engineers, Engineering Sustainability 158(2): 57–65.

Wang et al, 2008 LCA

Watson R T, Zakri A H (2009) Ecosystems and human well-being. Millennium Ecosystem Assessment, UNEP

Wheeler J (2004) One million sustainable homes. Industry and Environment. WWF UNEP: 26-27

Worldwatch Institute (2008) State of the World: Towards a Sustainable Global Economy: Ideas and Opportunities for Sustainable Economies, Earthscan ISBN 1844074986

WRAP (2009) Sustainability in Construction see http://aggregain.wrap.org.uk/sustainability/sustainability_in_construction/index.html (accessed June, 2010)

Wrisber N, Udo De Haes H A (2002) Analytical tools for environmental design and management in a systems perspective. Kluwer, Dordrecht

Yim K P (2005) Sustainability considerations in the design of slopes. See www.archsd.gov.hk/english/reports/e3120.pdf (accessed June, 2010)

Zavrl M S, Žarnic R, Šelih (2009) Multicriterial sustainability assessment of residential buildings. Baltic Journal on Sustainability 15(4): 612–630