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Sustainable Geotechnics

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Abstract
"Sustainable Geotechnics" may be considered as a discipline in ground engineering, appearing recently in the construction industry in response to the emerging Low Carbon Economy concerning the global challenges of climate change, diminishing fossil fuel reserves, and environmental management. In the UK Low Carbon Economy is often considered in terms of 'decarbonisation' of buildings, transport, industry, and power sector. This is to be addressed using a wide variety of sustainable approaches, which produce great challenges and opportunities to ground engineers. This paper discusses how the emerging Low Carbon Economy will affect the design and construction of low-carbon buildings and infrastructure as well as innovation covering some of the sustainable approaches recognized by ground engineering communities.

Keywords: Climate Change, Ground Engineering, Low Carbon Economy, Sustainable Development, Zero Carbon.

1. Introduction

1.1 Climate Change, Sustainability and Carbon

Over the recent decades, industrial activities and life style have been consuming an enormous amount of natural resources such as burning of fossil fuels and deforestation creating large volumes of waste material as well as greenhouse gases, which are seen to be responsible for climate change and its dramatic impacts [1, 2]. The impact of industrial activities on the world has grown during recent decades including many environmental issues [3], heat and cold waves, storms, floods and droughts [4], and energy crisis.

There is an increasing recognition that the capacity of the earth to absorb the impacts of human activity is not infinite, and is quite sensitive to everything that we do. These concerns are often linked to "sustainable development", which is a way of aiming to improve the economic, social and environmental well-being of communities, now and in the future.

The term "sustainable development" has clearly appeared at an international scale since the 96th plenary meeting of the United Nations General Assembly in 1987 [5]. Sustainable development became a key national and international policy in the 21st century. To assess the performance of sustainable development, there are many considerations – sometimes conflicting with each other – but the followings are the main principles of sustainability (see Table 1) which have been adopted by One Planet Living (OPL) [6] as a framework to help us enjoy a high quality of life within a fair share of the earth's resources.

Table 1: The main principles of sustainable development adopted by OPL [6]

	10 Principles
1	Zero Carbon
2	Zero Waste
3	Sustainable Transport
4	Local and Sustainable Materials
5	Local and Sustainable food
6	Sustainable Water
7	Natural Habitats and Wildlife
8	Culture and Heritage
9	Equity and Fair Trade
10	Health and Happiness

Many believe that “Zero carbon” should be on top of the list (as shown in Table 1), because there is a threat to each component of sustainability if carbon dioxide emissions are not tackled. It is clear that carbon has now provided a focus for political action that very soon we will be required to design, to tender, to construct and to operate our buildings and infrastructure to a carbon budget as well as a financial budget [7].

1.2 Carbon, Construction industry and Ground Engineering

The construction sector, where ground engineering can play an effective role, is responsible for at least 13% of emissions [8] along with manufacturing (see Figure 1). This presents opportunities to reduce carbon and greenhouse gas emissions including the reduction of primary energy uses. For example in transportation, where engineers are involved in the planning, design and construction of transport systems, great opportunities exist to contribute significantly through the whole life cycle of the process e.g. opportunities from reduction in deforestation at route selection and alignments, to construction techniques, through to reduction of energy use during operation e.g. gradients, lighting and ventilation of tunnels [9].

Construction may contribute directly and indirectly to the emission of greenhouse gases, due to energy used for raw material extraction, transporting, constructing, operating, maintaining and demolition. However the relationship between construction industry and sustainable development in terms of carbon emission is complicated and requires understanding of the concepts of embodied carbon, embodied energy, operational carbon, carbon footprint, and whole life carbon. Further carbon concepts such as “Carbon Critical Design” have been suggested [10] making carbon the primary design determinant for projects to reduce our consumption of fossil fuels.

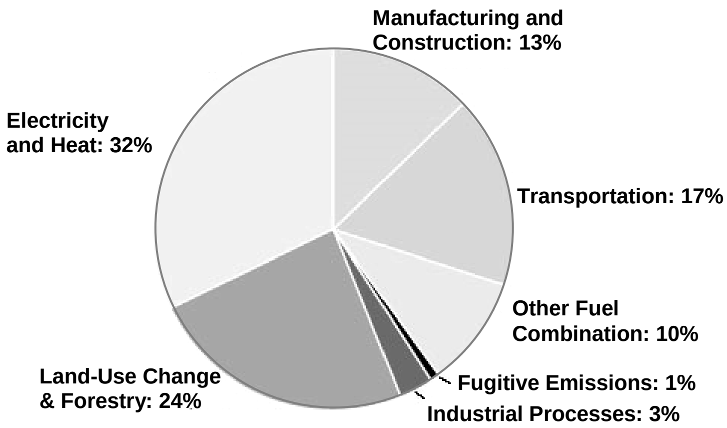

Figure 1: Global carbon emissions by sector (2006) [8]

In response to the challenge of moving sustainability from theory into practice, many consultants and governmental agencies in the UK have developed new tools, such as Sustainable Project Appraisal Routine[11] which has been developed based on a four quadrant model that structures the issues of sustainability into a framework, from which an appraisal of performance can be undertaken. Furthermore, carbon calculation tools have been created to compare the carbon emissions for different design solutions [10, 40, 41, 42]. These tools can be used as a model to follow however they are far too general to create a specific evaluation model for geotechnical aspects.

2. Low Carbon Project Cycle and Ground Engineers

2.1 Role of ground engineers at planning stage

The greatest influence on a project's environmental or carbon footprint may be achieved at the planning stage [9]. Ground engineers (including geotechnical engineers, engineering geologists and geo-environmental engineers) being at the beginning of the construction process may have significant potential to improve the sustainability of projects in the earlier stages of the decision making process. For example selecting the project location right would avoid destroying woodland so that it is easily accessible to operators and users by public transport; or the horizontal or vertical alignment of a pipeline, road or tunnel requires the least operational energy – little need for pumping or for trains to expend energy running up hill. If ground engineers could find ways of constructing infrastructure in well-located but challenging conditions, then their skills would be of significant carbon-saving value.

2.2 Geotechnical design solutions and principles of sustainability

At design stage some construction projects have already started to allow optimum choice of sustainable solutions to be considered particularly in relation to waste management, fill material, foundation type, and earth support methods which cause least harm to the environment. Table 2 presents details on some of these solutions adopted in practice.

Table 2: Some of the "sustainable" solutions adopted in ground engineering

Strategies	Implemented example solutions

Waste management strategies:
 	
Reduction, Reuse/ Remediation, Recycle, Recovery
	• Maximise the use of materials on-site to reduce the import of scarce natural resources and the export of surplus materials (and reducing transport of material to site)
	• Reuse and recycling of low risk contaminated materials in a controlled manner without causing pollution of the environment or harm to human health [12, 13].
	• Precise, safe and effective replacement of highly contaminated materials. This reduces transport requirements – for trucking out contaminated soil and trucking in clean fill [13].
	• Produce energy from waste [14]
	• Using a number of remediation techniques such as soil washing, bioremediation and sorting to remediate the soil in the most effective way to reuse it [15].
	• Amend specification for fill materials (used in construction) allowing for example:
	  o a higher content of old timber/other organic material.
	  o Reuse of clay fills as backfill to structures e.g. behind bridge abutment and retaining walls (i.e. the materials used in these locations are usually imported granular fill).
	• Treated water re-used on site for dust dampening
	• Demolition waste reused as crushed concrete fill [16]
	• Innovative use of recycled materials including: Ash Materials, Crushed Glass (GG), Quarry Fines and Spoils, Construction and Demolition (C&D) Material, Dredged Material (DM), Scrap Tyres and

	Tyre Derived Aggregate (TDA), Recycled Crushed Concrete (RCC) [17, 18]
Earth support methods	Slopes are stabilized using ground reinforcement techniques as alternative to concrete retaining walls, which have a significant amount of embedded carbon. Ground reinforcement techniques used: • Geogrid and soil nails [19] • Recycled plastic pins [20] • Fibre reinforcement [21] • Vegetation including willow poles [22] • Electrokinetic stabilisation of clay earthwork [23]
Energy and foundation	• Geothermal heating and cooling [24]: e.g. energy piles, segmental tunnels. • Tyre Bale foundation for earthwork on soft ground [25] • Use of cellular geo-cell mattresses [26] as embankment foundations • Reuse of existing and old foundations [27]

However a key issue for debate will be how are these sustainability measures contributing to carbon reductions. The carbon calculation tools that have been developed recently are very general and there is no established system that assesses the sustainability of a geotechnical project and encompasses the three core pillars of sustainable development (Economic, Environmental and Social) [28]. Therefore many ground engineers have found the idea of sustainable design "too hard" and increased the call for new models and simple tools to help the designer and employer to make better decision.

A comprehensive – yet simple - set of performance indicators can aid ground engineers to measure sustainability in their design solutions giving consideration to whole life carbon emission and costs and embodied energy as potential measures of sustainability. Trial application of the indicators to typical construction and comparison between procurement methods are essential to validate these indicators.

Furthermore, there is a need for new tools of risk management, incorporating carbon risk in addition to money and time, to help ground engineers to quantify what are the carbon threats and opportunities from delivering a project or making a particular change [29].

2.3 Development of construction efficiency and innovation

As many of the concerns associated with the sustainable development are directly related to construction, civil and ground engineering are certainly required to develop the construction efficiency by improving the existing methods and technologies [30]. Inefficient construction is likely to increase waste, costs and carbon footprint.

Table 3 presents some areas where significant improvement is needed. In site characterization – for example - advances in ground investigation technology over the last three decades have been limited [31]. However, some improvement has been achieved after the use of Geographic Information Systems as well as Building Information Modelling (BIM), improving our ability to store, retrieve, manage and display large quantities of diverse types of information on projects covering large areas [31, 32].

Table 3: Suggestion for improvement of construction efficiency in geotechnical engineering

Area of development	**Suggested development**
Ground characterization	Further improvement may be achieved by: • Improving inspection efficiency of ground and earthwork e.g. the use of Ground Penetration Radar (GPR) combined with 3D laser scanning of the surface and numerical modelling has shown very promising results [33] in this area. • developing comprehensive databases of ground condition e.g. Development of a Web-GIS based geotechnical information system [34-10c] with efficient integration with Building Information Modelling (BIM). • advanced algorithms for reliable interpretation of ground investigation data, which can potentially reduce cost, increase coverage, and reduce uncertainty in subsurface characterization. • Minimizing the impact of uncertainty over underground conditions and material response can also be reduced by using adaptive management and observational approaches to construction activities [31]. Adaptive management techniques allow one to automate the observational approach so that quantitative information can be distributed to interested shareholders efficiently and on time to make an informed decision.
Underground construction	Development of more efficient and economical underground construction techniques, minimizing environmental impacts of construction activities. The need for this development is becoming more critical with the rapid increases of urbanization.

	Geological prediction and geotechnical assessment are globally acknowledged as deserving a high priority for improvement, since ground and water conditions are controlling factors in choosing both the design and construction method underground [35].
Ground improvement	Development of more efficient and less disruptive ground improvement techniques, particularly for wet and weak ground. This improvement is particularly needed in the UK for the transportation infrastructure earthworks (e.g. Highway and Railway embankment slopes), where many of these slopes are old and suffer high incidents of instability [36]. This area may benefit from the consideration of soil as a living ecosystem, which can potentially offer innovative and sustainable solutions to geotechnical problems [37].

The development of the existing construction methods and technologies is helpful but it will not meet the carbon targets demanded in Climate Change Acts [29]. To reduce carbon emission to the extent required it is essential to accelerate the innovation cycle in civil and ground engineering and make better use of our research base and strengthen our capability to take up new knowledge across industry [7].

"Decarbonising" the construction sector does not necessarily imply less construction growth. It perhaps means develop an entirely new perspective on infrastructure i.e. constructing different forms of infrastructure using new innovative methods and materials. Thus, it is vital to explore approaches that ground engineering should pursue to achieve this vision in construction industry.

Research in the discipline of ground engineering has already begun to broaden from its traditional science of soil and rock mechanics [31]. Now we are concerned with the life cycles of the materials (from extraction of raw materials to structural failure and rebuild) and the long-term environmental effects of energy supply. There is real potential for breakthroughs and there are exciting opportunities for ground engineers if they become involved in biotechnology, nanotechnology and advances information technology [31].

For engineers involved in "sustainable geotechnics" the need for urgent research and rapid implementation is vital because many of the concerns associated with the sustainable development are directly related to ground engineering including (in addition to construction industry) problems related to environmental health, resource conservation and availability, safe disposal of chemical and nuclear wastes, clean up of contaminated sites, underground gas and carbon storage, pipelines, and building foundations.

3. New Approaches to Ground Engineering Education

A major challenge for the future is that engineers will need to be able to understand and implement highly technical solutions in concert with meeting the needs of economical constraints and societal concerns [38]. This future for ground engineering can be realized by a workforce that is broadly educated, able to adapt to emerging problems and technologies, and representative of all segments of society. This workforce can not achieve this without the support from academia and industry.

University system can help students, the future workforce, to develop interest in sustainable design, give them the tools and knowledge they need to influence the future of a sustainable society, encourage dialogue between different fields of design, and provide modules that facilitate and rewards interdisciplinary education and research.

However higher education needs to change if engineering degrees are to become more relevant to the industry. A 2007 Royal Academy of Engineering publication [39], Educating Engineers for the 21st Century, reported that industry seeks engineering graduates who have "practical experience of real industrial environments". A new 'experience-led' engineering degree could be the best way of preparing graduates for work in the industry [39]. Engineering degrees aim to provide a firm grounding in the principles of engineering science and technology, while inculcating an engineering method and approach that enables graduates to enter the world of work and tackle "real world" problems with creative yet practical results.

4. Conclusions

Sustainability is seen as embracing a wide range of issues that engineers have to consider in projects, from biodiversity to employment. Zero Carbon or Low Carbon Economy is a key in order to make a difference to sustainable development. In addition to cost reduction, ground engineers now have to manage the carbon risk by reducing the carbon embodied in or used on the buildings and infrastructure they create. However, moving from the high carbon economy of the 20th Century to the low carbon economy of the 21st contains a large scale of the challenge.

In striving to achieve Low Carbon Economy or sustainability in the built environment, improved knowledge of the energy/carbon footprint of current ground operations, new models and tools for design and delivery are essential but not adequate. To meet the carbon reduction target, it is required an accelerated innovation cycle in civil and ground engineering, making better use of our research base and strengthening our capability to take up new knowledge across industry.

Ground engineering is a field of engineering most closely aligned with issues of sustainability, and this field should take a leadership role in the primary challenge of our time. This vision requires our educational, research, and industrial institutions to embrace the art of interdisciplinary work.

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