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# Sustainable Design Education to Meet the Ever-Changing Worlds of Civil Engineering and Urban Infrastructure Systems

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## Abstract

Teaching civil engineers of the future the planning, design and construction of sustainable urban infrastructure systems is a multifaceted challenge. This paper presents case studies from two universities in the United Kingdom that design and deliver teaching modules in sustainable construction. The case studies presented here are integral to the curriculum design and delivery of a module entitled 'Sustainable Construction' offered to the first year undergraduate students registered at Teesside University and another, multidisciplinary design module called 'Design of Sustainable Engineering Systems2 (DSES2)' offered to the second year civil engineering students at Newcastle University. The academic institutions and the engineering professions as a whole have sincere intentions of imparting intellectual and technical capabilities consistent with Sustainable Design (SD) and so they must invest in the creation of learning environments that are appropriate for Sustainable Design education. The universities owning the modules presented in this paper have recognized the challenges associated with the delivery of SD skills among their students. This appreciation of the difficulties led them to innovate and as a result they were able to introduce novel changes to the curriculum delivery of civil engineering programmes. The authors for this paper have been using a range of different pedagogic strategies including problem-based, design-based and self-directed learning methods in their efforts to deliver SD concepts in urban environments. Particular attention is paid to the epistemic methods that are transferable in nature and can be implemented by other academic institutions delivering Sustainable Design education to their students from science and engineering degree programmes.

**Keywords:** Civil Engineering, Higher Education, Multidisciplinary Design, Problem-Based Learning, Self-Directed Learning, Sustainability

## 1. Introduction

The Twentieth Century had been a testament for the mankind's insatiable want of material wealth and his extraordinary capacity for consuming natural resources. This mind set and behaviour has resulted in the continual erosion of natural resources and almost irreversible devastation of the environment[1]. The consequences of the collective choices made during the last two centuries have not only upset the rhythm of the natural environment but have also disrupted the lives of ordinary people by perpetuating inequity and injustice across all nation states. The human world is rather intricately dependent upon the surrounding natural systems and only by recognising these complex sets of relationships that the sustainable development can be achieved in its true sense[2]. Universities have a very important role in making sustainability a reality. Through conducting research and delivering a range of different educational programmes, Higher Education (HE) institutions can affect positive contributions in the realisation of Sustainable Development (SD).

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New construction projects designed and delivered by the engineering professionals, especially civil and structural engineers must satisfy sustainability requirements while meeting the well-established principles such as efficient design, economy, safety and buildability[3,4]. While recognising the importance of sustainability, the Institution of Civil Engineers (ICE), UK which plays a key role in the advancement of the profession, urges its members of all grades to receive education and training in sustainability[5]. The sustainable development education given to the students on HE programmes must be multidisciplinary in nature and cover the issues surrounding the three pillars of sustainability: The environmental, the social and the equitable economic distribution[6,7]. It is worth highlighting that delivering sustainable design skills to the students on engineering programmes is not an easy task[4,8,9]. This paper presents case studies describing two modules delivered at two different universities based in the Northeast of England. The first case study is around the design of a module called 'Sustainable Construction (SC)' that was delivered to first year students on the civil engineering Undergraduate (UG) courses offered at Teesside University. The subsequent case study is a module called 'Design of Sustainable Engineering Systems2 (DSES2)' that was delivered to the second year students on civil engineering programmes at Newcastle University.

The modern day engineers can no longer appeal to the wider community with just their analytical and problem solving skills as they are also increasingly needed to demonstrate a deep sense of socio-environmental consciousness[10–13]. The modules presented in this paper do address these needs as the academics delivering these modules are mindful of the recommendations of 'Education for Sustainable Development Toolkit[14]', which states:

*"Education for Sustainable Development (ESD) must be locally relevant and culturally appropriate, reflecting the environmental, economic, and social conditions of your community."*

The following sections of this paper shall provide an overview of the contexts surrounding these modules and demonstrate the teaching and learning and assessment models used in the successful delivery of these modules. The authors believe that the models presented in this paper are transferrable and can be used by the academics teaching similar programmes at other universities. The Undergraduate and postgraduate courses in civil engineering offered by both Teesside University and Newcastle University are accredited by the Joint Board of Moderators (JBM), a consortium of four major civil engineering professional bodies in the UK.

## 2. Sustainable Construction

### 2.1 Sustainable Design Education at Teesside University

The key features of the Civil Engineering programme at UG level offered by the Teesside University include design-based learning, employability skills richly ingrained throughout the three years of the bachelors programme and sustainability education in the form of taught modules and final year research projects. One of the modules that invite and engage the students in environmental issues and SD is 'CEN1000-NSustainable Construction (SC)' a module offered to the first year students on the programme. This module gets students to engage in research informed discussions on areas such as environmental impacts of construction in cities[3], SD, life cycle analysis[15], resource efficiency, climate change[16], Sustainable Urban Drainage Systems (SUDS) and environmental assessment[17]. The underpinning concepts are delivered through a series of lectures with a strong emphasis on case studies of live and completed projects that were either successful or unsuccessful in meeting the sustainability criteria set by standards such as 'Code for Sustainable Homes (CSH)' and 'Civil Engineering Environmental Quality Assessment (CEEQUAL)'. As noted by Bond et al.[18], the process of conducting Environmental Impact Assessment (EIA) draws on knowledge arrangements that are multidisciplinary in nature and hence, is most effective when done in multidisciplinary teams. The academic team delivering this module recognise the importance of teamwork in achieving effective knowledge transfer, so they have made teamworking an integral element to students' participation in this module. The assessment for this module takes the form of a 2000 word technical report written by the students individually. In this report, the students are expected to appraise real civil engineering problems for their effectiveness in satisfying the requirements of the three pillars of sustainability: Environmental, social and economic. The learning and teaching and assessment model used in this module is best described in Figure 1.

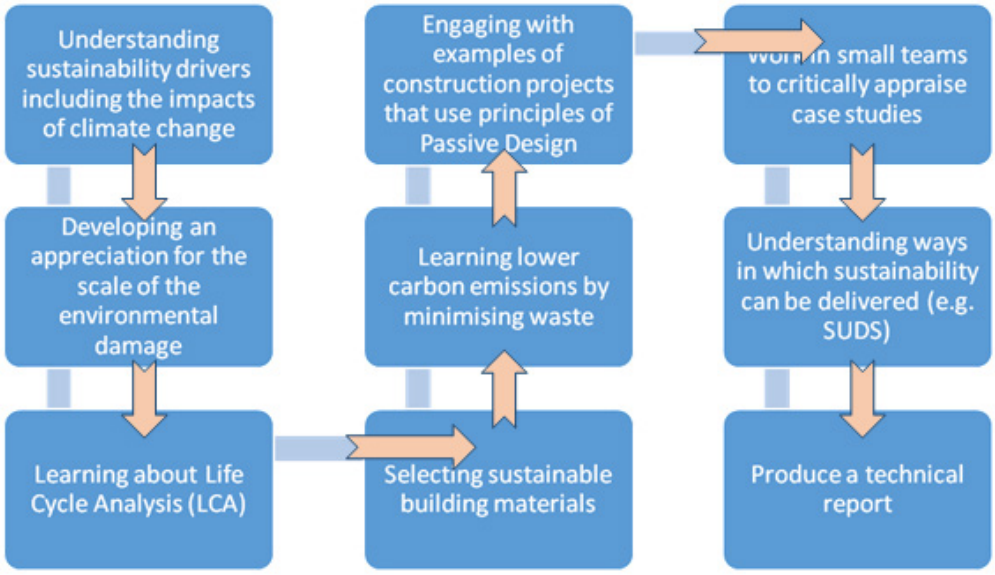


**Figure 1.** CEN1000-N sustainable construction teaching and assessment model.

## 3. Design of Sustainable Engineering Systems

### 3.1 Sustainable Design Education at Newcastle University

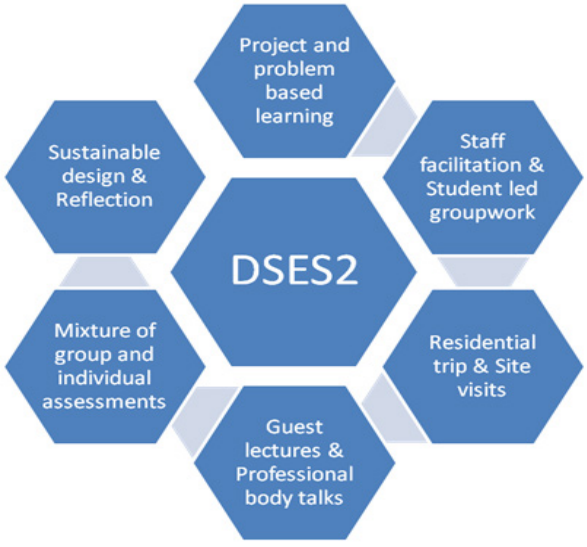


**Figure 2.** CEG2001 design of sustainable engineering systems 2teaching and assessment model.

The curriculum for UG Civil Engineering at Newcastle University is layered vertically into themes which run across the three years of the programme. One of those themes is a set of modules which builds students' understanding of sustainability issues and is called 'CEG2001 Design of Sustainable Engineering Systems (DSES)'. This theme serves well to integrate the concepts and skills learnt from the other, more traditional civil engineering modules. The module discussed in this paper, DSES2 is from the fore mentioned DSES theme and is delivered to the students on the second year of UG civil engineering programme. The teaching and assessment model outlined in Figure 2 is explained in greater detail by Vemury et al.[19].

### 3.2 The Design Brief

The module delivered at Newcastle University is primarily a group-based design module where students are required to address the requirements set by the design brief. Students are introduced to the underpinning knowledge areas through a series of lectures, field visits to large scale infrastructure design schemes and guest lectures from leading experts in areas such as bridge and tunnel design and sustainable construction. The River Tyne which runs through the Northeast of England acts as a barrier to the movement of people and goods between the urban areas in the North and the South of the river. This issue has been addressed through the construction of several bridges (for road, rail and more recently for pedestrians and cyclists) across the river. A tunnel referred to as 'Tyne Tunnel 1' was opened in 1967 to facilitate the crossing of vehicular traffic across the River Tyne. However, by the beginning

of the millennium year this tunnel was operating well above its design capacity and as a result has now become barrier to economic growth in the region 'A19'. It is worth noting that the roads classified as 'A' roads in the UK are of national significance and carry people and goods between cities and major towns[20]. A second tunnel not much further away from the Tyne Tunnel 1 had been built in 2011 in order to meet the prevailing traffic congestion issues. Despite having a series a bridges and two tunnels to carry rail and road traffic, there continues a growing need for further avenues of transport across the River Tyne. The network of roads and the tunnels servicing the region are indicated in Figure 3. The design brief given to the students on DSES2 requires the students, working in their groups to conduct feasibility studies followed by a detailed design of a transport infrastructure system that provides an efficient crossing over the River Tyne. While exploring various feasibility options and carrying out detailed conceptual designs, the students are expected to honour the three pillars of sustainability (i.e. social, economic and environmental). The structural concept developed by the students must be iconic and add value to the local community.

## 4. Conclusions and Lessons Learned

The two modules presented in this paper highlight the use of real civil engineering problems and group-based teaching as effective tools for engendering sustainability thinking among students. The module from Teesside University actively engages students to critically review live and completed examples of civil engineering projects. In DSES 2, the students are invited to design a river-crossing which is a well-documented transport problem as faced by one of the key cities in the North of England. The students enrolled on both of the case studies (or modules) presented in this paper are actively encouraged to think deeply about sustainability while attempting to complete their assessments for these respective modules. These modules are not delivered in isolation as they integrate the knowledge and skills gained in other civil engineering modules. SC delves deeply into life cycle analysis, resource efficient design, SUDS, standards such as CEEQUAL whereas the DSES 2 brings all important aspects of a large scale infrastructure project such as master planning, site investigation, geotechnical design, structural design, hydraulics, transport, materials, specification and environmental and sustainability assessments[19]. The transferable skills gained through these modules including problem formulation and identification, effective oral and written communication, multi-criteria design, value judgement and advocacy, developing engineering drawings and reports give students an excellent standing when they embark upon other academic or real design projects. As suggested by Bedoya-Valencia et al.[21], the three main components namely knowledge, awareness and raising perception

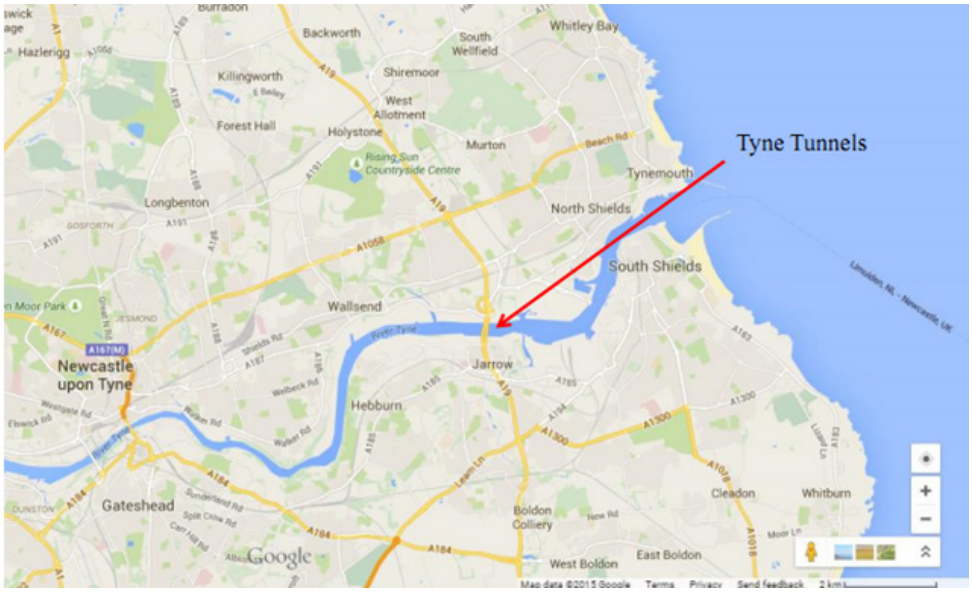


**Figure 3.** River Tyne and surrounding road network. (Source: Google Maps).

were taken into account while evaluating the effectiveness of the two case studies presented.

The teaching methods and strategies used by the module leaders of SC and DSES 2 are transferable and may well be used by academics teaching sustainable design to engineering students. Based on the feedback given by the students enrolled on these modules, the accrediting body called Joint Board of Moderators (JBM) and the local employers who have recruited graduates from these respective universities, it can be said that these modules have been instrumental in enhancing students' awareness of environmental issues, sustainability and the role of civil engineers in delivering sustainability.

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