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Sustainability Principles and Their Integration into a Higher Education Mechanical Engineering Undergraduate Programme

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Introduction

Current undergraduate engineering programs tend to be organised along fairly standard engineering themes such as mechanical engineering or automotive engineering. The engineering institutions have made it plain that sustainability needs to be a fundamental element of all mechanical engineering themed courses yet in reality only a tiny minority of modules make reference to sustainability. It is true, however that sustainability is a subject with such a large depth and breadth that the subject could be dedicated to whole degree courses. This paper defines the Principles of Sustainability [4] and suggests several types of degree program through which sustainability can be introduced into a higher education, undergraduate mechanical engineering scheme. The paper explains that sustainability can only be taught through the medium of design since the design function is the only function which has an overview and can influence the life of a product from "cradle to grave".

The Principles of Sustainability

Environmental awareness has been a growing issue throughout the 20th century largely driven by health risks created by pollution. Generally environmentalists were a lone voice until 1975 when scientists began to recognise that gradually rising worldwide temperatures was becoming a global issue which could seriously inhibit the human race. In the ensuing years after 1975 scientific studies caught the attention of many governments to collectively instigate dynamics which would improve the environment. Much of this work is directed at reducing carbon footprints but this is merely a small element in caring for the global environment.

The human race is an avaricious user of consumables which not only give off "greenhouse gases" but extract non-renewable resources from the environment in order to manufacture and use these devices. The creative processes of engineering can apply The Principles of Sustainability [4] taking a whole-life view of products and services and reducing the "take" from the environment.

True Sustainability.....

..... is development and use of products and services where ZERO resources are taken from the Earth

Sustainable strategies may assist in reducing the environmental impact but the reality exists that it may NEVER be possible to achieve true sustainability. Appropriate sustainable strategies may however help us to come close to attaining the sustainable "Holy Grail".

The Integration of Sustainability through Engineering Design

The original methodology of design and manufacture concentrates on the creation of products without any consideration of material sourcing or how those products are to be used or for any consideration of the disposal process. An integrated approach sees the designer creating new products whilst considering the whole life of the product.

There are six elements which comprise the whole-life span of a product. These are shown in figure 1. This model shows that the design function is the only function that can overview the whole creation process and indeed it is the only function that can specify elements of sustainability for a new product.

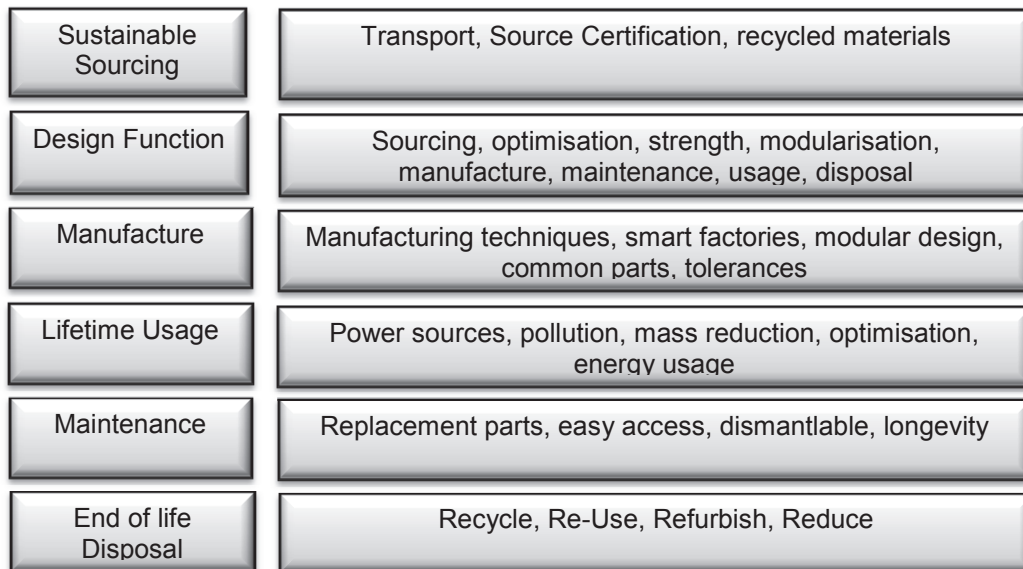


Figure 1: The Six Elements of the Sustainable Engineering Whole Life Model

This new model enhances the classic design and manufacture model and incorporates six elements of sustainability which can be applied to the whole life view of a new product.

These are listed below:

1. sustainable sourcing
2. sustainable design techniques
3. design for sustainable manufacture
4. design for sustainable use
5. design for sustainable maintenance
6. design for sustainable disposal

Embodied Energy

A model such as that in figure 1 is a very useful guide but practising designers require sustainability to be quantified. When a product is created the use of energy is the single commodity which is applied from extraction from the Earth through the product's life to its eventual disposal. The value of energy, therefore, can be used as the measurement quantity for the evaluation of sustainability. Defining the energy used in various operations and processes is a multifarious task and has been managed to a greater extent by the use of CES EduPack software from Granta Design Ltd of Cambridge.

For any component parameters such as processes, machining, transport and several other details can the input to create a whole-life view of the energy needed to create a product. This is termed "Embodied Energy" and it is the design engineer's task to reduce the embodied energy within any product. The use of energy as measuring parameter also allows carbon footprint to be measured since energy used in processing is often directly related to fossil fuel powered engines. CES EduPack software also easily converts Embodied Energy (MJ) into Carbon Footprint (Tonnes CO₂)

Sustainability in Mechanical Engineering Undergraduate Education

Engineering institutions such as the Institution of Mechanical Engineers (I.Mech.E) [1] and the American Society of Mechanical Engineers (ASME) [2] understand the importance of educating young mechanical engineers in sustainability techniques. Through the accreditation process the aim of the institutions is to train young engineers during their undergraduate degree programmes so that on graduation these budding engineers can integrate schemes of sustainability into working practice. This involves close adherence to the "UK Spec" [3] which is the definitive guide for the accreditation of undergraduate engineering programs. In the UK The Engineering Council (body that grants chartered status) has developed a six-point guidance document aimed at assisting engineers in applying the principles of sustainability during their work practice.

The six points are listed below and are embodied in any undergraduate degree program if accreditation is to be approved:

1. contribute to building a sustainable society
2. apply professional and responsible judgement
3. comply with legislation and codes
4. use resources efficiently and effectively
5. Seek multiple views to solve sustainability challenges
6. manage risk to minimise impact people or the environment

Education is the Key

Sustainability is an enormous subject needs to be introduced to undergraduates at an appropriate pace. Young engineers (and much of industry) require structure when applying the Principles of Sustainability and that can be best integrated within the engineering design element of an undergraduate course. Engineering design runs through all levels of an undergraduate degree program consolidating and integrating ALL the other subjects rather like the hub of a cartwheel combines all the spokes.

Engineering design is also the only function that can give a true "whole-life" overview in terms of defining material sourcing, design, manufacturing, usage, maintenance and disposal. Design is also the only function that can consider and implement the objectives of the "Triple Bottom Line" [4] which are listed as follows:

Objective 1: To create profit for the company (the designer can then prosper)

Objective 2 To create a product, which will enhance the lifestyle of other human beings

Objective 3: Sustainable development of the whole product lifecycle (which helps the planet to survive)

Industry has always striven to achieve the first two bottom lines, Objectives 1 and 2, which has always been to make a profit and to create goods and services to enhance human lifestyle. The third bottom line is now incumbent on all engineers to develop goods and services which are *sustainable* incorporating the least impact on the planet.

Integration into Teaching Undergraduate Mechanical Engineering Degree Program

The Principles of Sustainability on an undergraduate mechanical engineering course needs to be introduced systematically throughout all levels of the course. The general approach would be to impart the basic theory of sustainability in year one, progressing to a deeper understanding in year two with the introduction of measurement methods in final year. This approach can be taken if sustainability is to be integrated into a current Mechanical Engineering degree program however there are other approaches depending on the evolution of the subject and commitment of the host institution.

There are three major approaches:

- *Integrate sustainability within a mechanical engineering undergraduate programme* as part of the normal course structure. Sustainability would be delivered through the design modules at each level. This undergraduate programme may have a title of "Mechanical Engineering".
- *Integrate sustainability as a major course flavour into a mechanical engineering undergraduate programme.* This course may have a title of "Mechanical Engineering with Sustainability".
- *Introduce a dedicated sustainability undergraduate engineering programme where all subjects are taught from a sustainability point of view.* This course may have a title of "Sustainable Engineering"

Masters Level Courses

Teaching of sustainability within Masters level courses needs to be more precise and aimed at practitioners rather than theorists.

The University of Huddersfield, Department of Engineering and Technology Approach.

Initially driven by the institution of mechanical engineers as part of their accreditation process sustainability was introduced within the Professional Studies module in year one and also in the Engineering Design module in year two. The programme has evolved so that currently there is a greater emphasis on the Principles of Sustainability taught at second year within the Engineering Design module. A final year module has also recently been introduced which reintroduces the theory and discusses it in much more depth. Furthermore the final year module includes methods of quantifying sustainability and defines methods as to how practising design engineers can apply the Principles of Sustainability to their work.

Similar Programs at the University of Huddersfield

During the last few years The Department of Engineering and Technology has been running BENG. (Hons) Energy Engineering programme which is a largely mechanical engineering but part electrical engineering programme where the "Energy Engineers" focus on the principles of energy creation and usage concentrating on alternative energy gleaning. The students also study the standard modules taught on the mechanical engineering programs which embody sustainable engineering principles.

The programme has been running for four years and has had reasonable success but discussions with the first exiting graduates suggest that the course focuses too much on energy creation and could benefit from a broader approach incorporating and applying the Principles of Sustainability.

Proposed New Course at the University of Huddersfield

In view of the feedback from students exiting the "Energy Engineering" program it is proposed that modifications are applied with suitable sustainability and related modules being inserted at each level. This is effectively creating a mechanical engineering degree program with a distinct flavour and relates to the second option of the teaching of sustainability principles outlined above.

The modified undergraduate programme would have a title of "Mechanical Engineering with Sustainability" and would be taught with the basic precept that graduates would be mechanical engineers but with knowledge and application of the Principles of Sustainability. The module outline can be seen in figure 2.

General Programme

Year 1: introduction to the Principles of Sustainability

Year 2: within the design function and in-depth explanation of the meaning of sustainability and an overview of its application within the design of products.

Year 3: Industrial Placement: endeavour to place students in companies who already apply or wish to integrate sustainability within the company and the product.

Year 4: the Principles of Sustainability are explained in depth along with methods of practical application and measurement of sustainability.

Year 5: (Masters Year) a single module would imbue the student with practical applications and methodology of sustainability principles. Essentially this would explain *how* to apply and quantify Principles of Sustainability.

Institution of Mechanical Engineers accreditation is thought to be grantable since "UK Spec" and the Institution of Mechanical Engineers own codes of practice suggest that design is fundamental to any undergraduate engineering programme and that the Principles of Sustainability should be embodied in the teaching of engineering design.

Universities have a dual obligation to recruit students onto popular degree programs but also to service the requirements of industry. Many large companies are beginning to, or already have created posts of "Sustainability Engineer" in an effort to improve the sustainability value of their product creation process. These companies include: JCB, Cummins, Deutz, Caterpillar, and many more high profile institutions. With this in mind

there is expected to be almost full employment for graduates of such a course which combines the Principles of Sustainability with Mechanical Engineering.

The new course proposal meets the requirement of the Institution of Mechanical Engineers in that undergraduates should be trained in terms of sustainability so that a new generation of sustainable design engineers can take the "new education" into the

Year 1	Year 2	Year 3	Year 4	Year 5
NFM 2105 20 Manufacturing Tech + Workshop	NIM 2211 20 Mechanical Engineering	NFM 2105 120 Industrial Placement	NHM 2486 20 Eco Design and IPR	NMM NEW 15 Renewable Energy Systems + Storage
NFM 2104 20 Engineering Comms & Materials	NID 2218 20 CAD/CAM		NHM NEW 20 Advanced Design Principles & Practice	NMM NEW 15 Eco Management & Eco Audit Methods
NFM 2167 20 Professional Studies and IT	NIM 2238 20 Thermofluids		NHM 2405 20 Advanced Energy Systems	NMM 3515 15 Advanced Static Analysis
NFE 2158 20 Electrical Principles 1	NIE 2299 20 Electrical Principles 2		NHM 2410 40 Final Year Project	NFM 2105 45 Group Project
NFM 2504 20 Mathematics	NIM 2288 20 Dynamics		NHA 2416 20 Aerodynamics and CFD	NMM3531 15 New Product Development
NFA 2168 20 Mechanical Eng. Science	NIM 2287 20 Analysis of Materials		NIM 2486 20 Electrical Power and Machines OPTION	BM006 15 Finance for Managers OPTION
Modules Containing Sustainability Principles				NMM3530 15 Project Management OPTION

Figure 2: Proposed U/G Programme "Mechanical Engineering with Sustainability"

workplace and in so doing can influence currently practising engineers. The goal of the Institution of Mechanical Engineers is to empower, through education, a new generation of engineers to apply the Principles of Sustainability to their work.

Research shows that many higher educational institutions are launching new engineering courses which integrate sustainability. The education and recruitment of engineers will eventually meet the sustainability necessities of Small/Medium Enterprises (SME's) and also larger companies.

Research (Monster Recruitment) also shows that there is a burgeoning jobs market for "Sustainability and Environmental Engineers". The educational criteria for such posts are exactly what the proposed undergraduate programme will provide.

Jenny Hirst, Energy/Sustainability Engineer at Cummins, Huddersfield says, "there is a fast growing need for engineers who understand the Principles of Sustainability"

It is believed that the new course will provide an interesting programme for newly recruited students and an essential resource for industry.

References

- [1] Institution of Mechanical Engineers: 2013 Code of Practice
- [2] American Society of Mechanical Engineers: 2013 Code of Practice
- [3] The Engineering Council: 2013 UK Spec
- [4] Johnson AD, Gibson AG, Barrans SM: 2011: The Sustainable Engineering Design Model: Necessity or Luxury