25. What is Sustainable Technology?
A materials perspective for learning complexity in engineering

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Abstract

"Sustainability" is not a simple parameter that can be quantified and optimized in an engineering design. Issues of sustainability are intrinsically complex; their assessment requires acceptance of this complexity and working with it. Each facet (e.g. environment, society, regulations, design, materials…) can be explored in a systematic way but the integration of the facets to give a final assessment requires judgment and reflection, as there is no one single sustainable solution to a problem. Integrating the different articulations of SD needs a holistic approach and participation. How can we teach this to engineering students in a simple and effective way?

This paper presents the ideas behind new teaching resources for Sustainable Development, designed for courses of engineering and materials science. These resources recognize the complexity and multidisciplinarity surrounding issues of sustainability and new methodologies and tools to help student understand and analyse them.

This paper describes the reasoning behind the resources, which include a method and a database of background information. The outcome is, inevitably, subjective, influenced by social, cultural and political background and therefore one requiring debate, but the method creates a common background of accepted facts on which an informed debate can be based.

During 2013 the resources were trialled in a number of courses, providing some first experiences in a real educational setting. This paper summarises some of their outcomes.

1 Introduction

A "Sustainable Development" is one that contributes in an equitable way to human welfare and does so in a way that minimizes the drain on natural resources. Many academic, civil, commercial and legislative projects claim to do this – promoting biopolymers, carbon taxes, design for recycling are examples. Following Mulder et al. (2011) we shall refer to them as "articulations" of sustainable development. But how are they to be assessed? There is no simple, "right" answer to questions of sustainable development – instead, there is a thoughtful, well-researched response that recognizes the concerns of stakeholders, the conflicting priorities and the economic, legal and social constraints of a technology as well as its environmental legacy.

How can students be introduced to this complexity and equipped to assess the viability of projects that claim to be sustainable? The aim of the method described here is not to define a single metric of index of sustainability; rather it is to improve the quality of discussion by providing a reasoning-path and guided access to relevant data.

2 The three capitals

"Wealth" is a generic term for all that we value. Global or national "wealth" can be seen as the sum of three components: the net manufactured capital, the net human capital and the net natural capital (Dasgupta, 2010) and Fig. 1. They are defined like this.

- Manufactured capital ("Prosperity") – Industrial capacity, institutions, roads, built environment and financial wealth.
- Human capital ("People") – Health, education, skills, technical expertise, accumulated knowledge, happiness.
- Natural capital ("Planet") – Clean atmosphere, fresh water, fertile land, productive oceans, accessible minerals and fossil energy.

A narrow view of a Sustainable development is as a development that conserves Natural capital. A broader view is a development that takes in account the evolution of the three capitals, and aims at the increase of them, or minimal decrease of any of them. It is this second view that informs the method described below.

Fig. 1. The three Capitals and Sustainable Development

3 Analysing sustainable technologies

Examination of many articulations of sustainable development drawn from journals, conferences, national and international government publications suggests the following picture. Each articulation has a motivating target that we will refer to as its "Prime Objective". Each involves a set of Stakeholders. In assessing the sustainability of project the first step is to identify these: if the Prime Objective is not achievable or major Stakeholders are left dissatisfied, the project is unlikely to be sustainable. Further examination suggests that the central issues might be grouped under the six broad headings:

- Materials and Manufacture: supply-chain risk, life-cycle demands and recycle potential.
- Design: product function, performance and safety.
- Environment: energy efficiency, resource conservation, preserving clean air, water and land.
- Regulation: awareness of, and compliance with, National and International Agreements, Legislation, Directives, Restrictions and Agreements.
- Society: individual health, education, shelter, employment, equity and happiness.
- Economics: the cost of the project, and the benefits that it might provide.

This suggests the following way of analyzing articulations of sustainable development. It has 5 steps (Fig 2). The first is a statement of Prime Objective, its scale and time envisage to achieve it (Step 1). Stakeholders are identified and their concerns listed (Step 2). These concerns are mapped onto a Fact-Finding search (Step 3) assembling data relevant to each of the headings listed above. This provides the background for a debate or discussion of the impact of these facts on Human, Natural and Manufactured capital (Step 4). The analysis ends with reflection on possible priority changes (Step 5). The first three steps are objective and deterministic; the last two are subjective, and therefore open to debate and creative thinking.

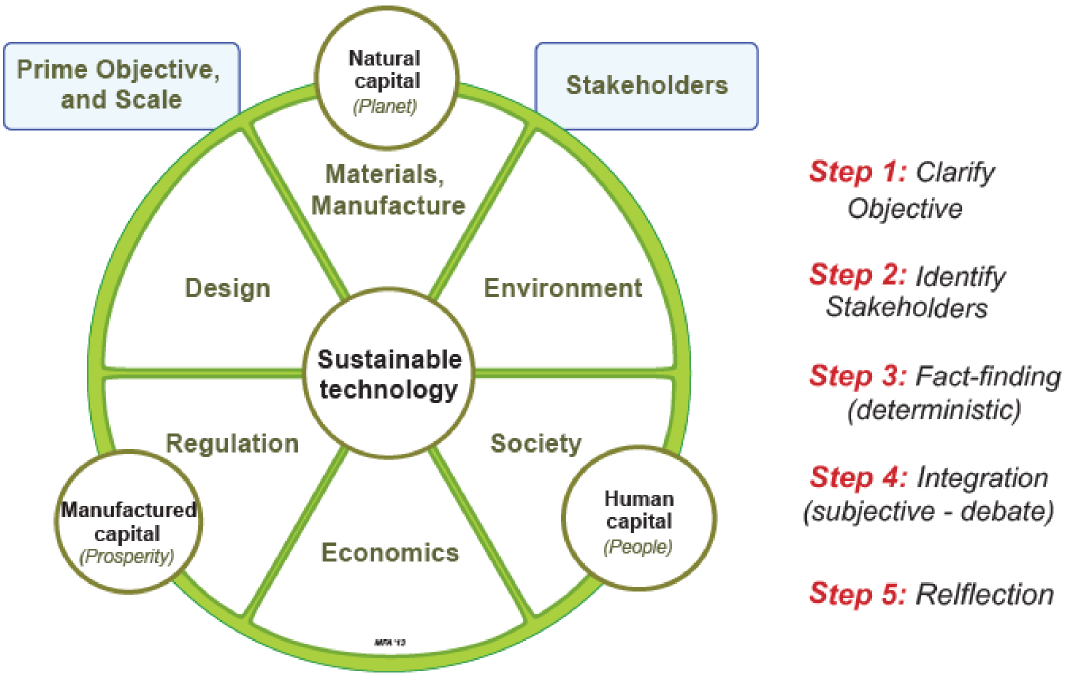

Fig. 2. The 5-step assessment of a Sustainable Development

4 The CES sustainability Database

The SUSTAINABILITY database (GrantaDesign, 2013) is designed to help with the fact-finding step It contains six linked data-tables (Fig. 3). At the center is the *Materials* data-table containing data for materials, their properties, eco-profile and nations from which they are sourced. It is linked to two data-tables relating to energy: one with records for *Electric-Power generating systems* (conventional, nuclear, renewable), the other for *Energy Storage systems* (chemical, potential, kinetic, electric). It is also linked to the data-table of *Regulation*, listing legislation, regulations and incentives to encourage or restrict the ways in which energy and materials are used. These two data-tables are linked to the *Nations of the World* data-table, which contains records for the world's 210 nations, with information about population, governance, economic development, energy use and engagement with human rights, together with information that may bear on security of supply of materials or services derived from that nation. The links connect related records; thus each material record is linked to records for the nations from which it is drawn and legislation bearing on its use.

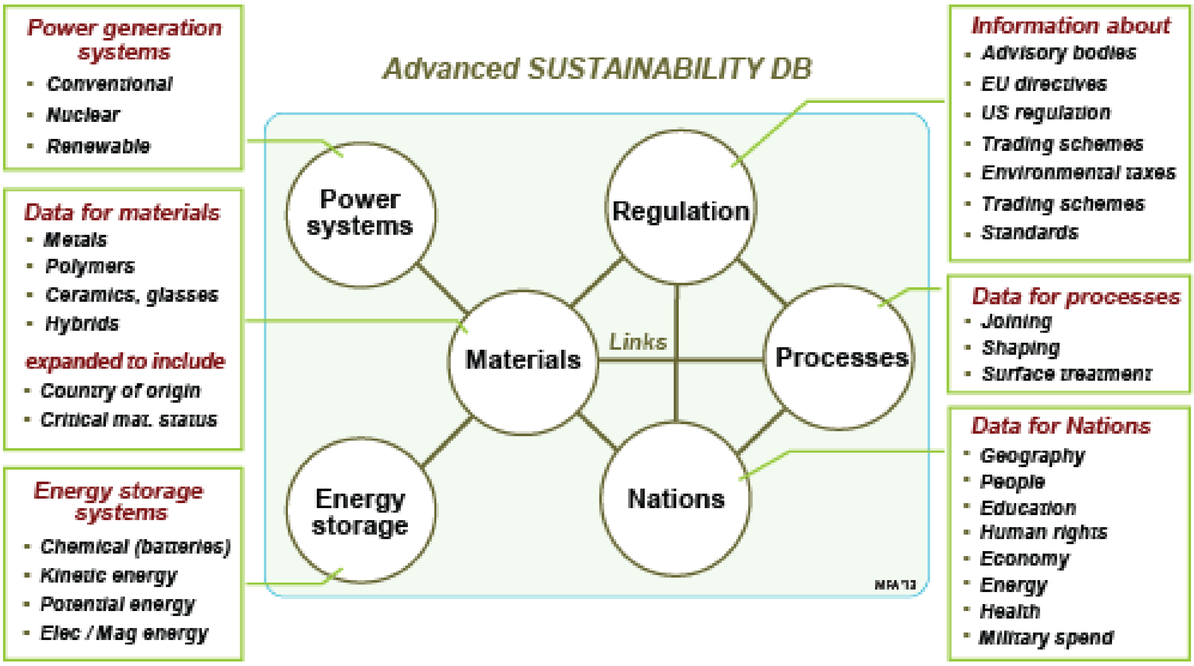

Fig. 3. The structure of the CES Sustainability database.

The analysis method and the database are fully documented in the Granta Design White Paper called Materials and Sustainable Development (Ashby and Ferrer, 2013). The White Paper illustrates the use of each of the data-tables and demonstrates the method by using the database as a whole as a fact-finding tool to explore two major articulations of sustainable development: wind farms, and electric cars. The White Paper and SUSTAINABILITY database help contextualize the role of materials in sustainable development and to expand competences in critical thinking about complex issues including resource use, legal barriers, ethical considerations and societal concerns.

5 Pilot experiences in education

The 5-step method and the SUSTAINABILITY database described here are contributions towards the difficult task of introducing students to the multi-dimensional aspects of Sustainable Development. It can be used for individual or for group projects. As a group activity, the role of a stakeholder and the responsibility for one fact-finding task can be assigned to each member of the group, the individuals research their assignation and report back to the group as a whole (Fig. 4). This is then followed by a group "debate" seeking consensus on the impact of each of the fact-finding searches on the three capitals. The analysis as whole has a purpose and conclusions: while the underlying problem may be complex, it is important to report the result in a simple manner, making them accessible to non-experts.

This teaching method can be suitable for different levels of depth, ranging from a session of few hours on sustainability, to a full semester course or a final project. In its pilot phase, the method is being tested in different universities.

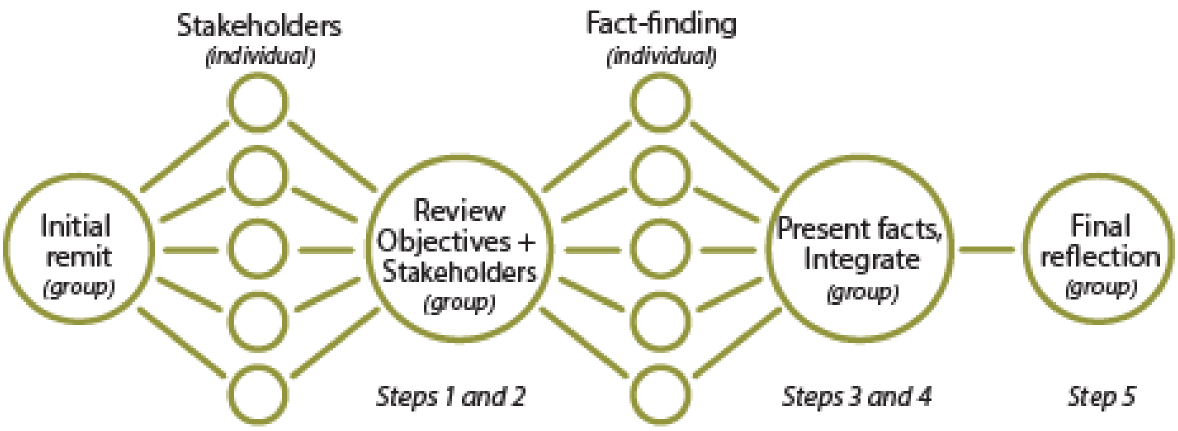

Fig. 4. Sustainable-technology assessment as a group activity.

5.1 *A pilot experience at UPC-Barcelona Tech*

"Sustainable Design" is a subject of the Master of Sustainability organized by UPC Barcelona Tech (5-ECTS, 1-semester). The subject uses constructive and community oriented learning for sustainable design. It is organized around three axes: Strategies, Tools and Projects. First, students are introduced to sustainable design strategies principles. Second, and as a pilot educational project, students use CES-Edupack 2013 using the Advanced SUSTAINABILITY database tool and finally, students apply the tool to a contextualized project taking into consideration the sustainable strategies available. The teachers of the course were familiar with sustainability concepts.

The 20 students spent aprox 50-60% of the course time on the group project (there was other content on sustainable design approaches). They presented the progress after each project phase. The topics were chosen by the students from a list proposed by the teachers, and finally were the following:

- District wind energy.
- Electric bus for urban mobility
- Electric cycle for urban mobility
- Nespresso coffee machine
- Bamboo for sustainable furniture
- Bamboo as alternative building material
- PV micro-generation of power

5.2 *Feed-back from students*

At the end of the course, students were asked to give their opinion about the teaching method, the tools and their learning progress. This evaluation is still in progress, so at the time this paper was written the assessment is still preliminary.

Students were provided with the White Paper (Ashby and Ferrer, 2013), the SUSTAINABILITY database, the CES EduPack software to run the database and given a 1 hour tutorial on how to use it.

The students appreciated the methodology as a holistic and practical approach to exploring sustainability. They commented that it gives guidance and focus while tackling the complexity of the task. They would like to see a complete example before starting their projects, to understand the full process. They thought the SUSTAINABILITY database helped to save time and find relevant information, and that the 1 hour introduction was useful (and asked if it is regularly updated – it is). They greatly appreciated the continuous feed-back from the teachers after each phase.

5.3 Feed-back from teachers

Students had difficulties formulating the Primary Objective, scale and envisaged time by which it should be achieved (Step 1) – more help in framing this would help. In analysing stakeholders (Step 2) students did not look for documented sources (such as News reports or magazine articles from pressure groups); instead, they found the list of stakeholders contained in the White Paper and speculated, without adequate basis, about their concerns. Projects requiring the assessment of a single articulation were more successful than those requiring a comparison of two or more alternatives, which became too complex. Students had difficulty with the integration phase (Step 4); to help clarifying it, a matrix between the 6 broad "headings" and the 3 Capitals was constructed and will be included in the next edition of the White Paper. The course ended with presentation by the students to the instructor and the rest of the class. On hindsight, it would be better to stage a meeting with student playing the role of stakeholders to stimulate critical discussion.

In reviewing the course, the instructors had the following reflections:

- Making the grading-grid available to the students gives them guidance in distributing their time.
- Students should understand from the start that the desired output of the project is a multi-dimensional sustainability assessment, exploring the idea, the project, the technology, and the process. Students should imagine that they have been commissioned to advise an interested party who will use the advice for decision-making. Students should defend their recommendation on sound data and integrated information.
- Ensure clarity of the primary objective and time-frame formulation. Examples of successful articulations (mandatory wearing of seat-belts in cars, for example) and failed articulations (the UK Government ground-nut scheme in Africa) could help here.
- Having two or more groups do the same project in parallel could reveal the best way to structure the integration phase, and be a valuable learning experience.
- Explain better the issues valued in the 3 capitals and the relationships between them, which students found difficult.
- Stage a role-playing session at the conclusion of the course. While one group is presenting, the other groups play the parts of principal stakeholders (as examples: the role of environmentalists for Natural capital, that of politicians or trade unionists for social capital, and that of investors or entrepreneurs the manufactured capital).

6 Summary and conclusions

"Sustainable technology" has many interpretations. Central to all is the concept of the value of natural capital (the planet's natural resources), of human capital (the health, education and social development of the human population of the planet) and of manufactured capital (the value of man-made institutions, infrastructure and wealth). The many different articulations of sustainable technology aim to support one or another of these but few support all three. Progress is possible only with well-balanced trade-offs and compromises between them.

This paper has presented a new teaching method and a supporting tool to be used in a systematic manner in engineering, design and materials courses. The first trials with teachers who were familiar with sustainability concepts reveal it to be useful, as it brings focus, guidance and concrete tools to the students and instructors.

7 Acknowledgement

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8 References

Ashby, M., Ferrer, D. and Bruce, J. (2013) “Materials and Sustainable Development– a White Paper”, Granta Design, Cambridge (www.grantadesign.com/education/)

CES EduPack (2013) and the SUSTAINTABILITY database is a product of Granta Design, Cambridge. UK. (http://grantadesign.com/education/overview.htm)

Dasgupta, P. (2010) “Natures role in sustaining economic development” Phil Trans Roy Soc B, Vol. 365, pp 5 – 11.

Mulder, K., Ferrer, D. and Van Lente, H. (2011) “What is sustainable technology” Greenleaf Publishing, Sheffield, UK. ISBN 978-1-906093-50-1.