Educational Software for a Sustainable Future

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Abstract

This *Work-in-progress paper describes the innovative practice of the* GRANTA *EduPack software for materials-related teaching that was originally developed as an educational tool for undergraduate teaching at the Engineering Department of Cambridge University some 30 years ago. The software introduced a revolutionary visual methodology for selecting materials based on application and desired performance. It has found extensive use in the teaching of mechanical engineering, product development and design, both in classroom settings and for project work. The progress of the work on this platform is showcased here.*

The software contains extensive databases of material properties and manufacturing processes. It has evolved with the introduction of eco-properties such as embodied energy, carbon footprint and water use for materials. In 2008, the Eco Audit tool was introduced, which enabled streamlined life-cycle inventories at the early stages of product design, and in 2013, a sustainability database was created and added. The latter contains information about, for example, sourcing and criticality of elements; materials-related legislation and regulations, geo-economic and social conditions data from all the nations of the world, as well as energy generation and storage. In parallel, a 5-step methodology for assessment of sustainable development of technologies exists.

The latest contribution to these innovative resources is a Beta-version of a Social Impact Audit Tool designed to introduce the concept of Social Life-Cycle Assessment (S-LCA) of products. The tool is implemented in EXCEL and is based on the widely accepted UNEP/SETAC "Guidelines for Social Life Cycle Assessment of Products", allowing students to explore scenarios that illustrate the S-LCA. This paper describes the progress outlined in the steps above and provides examples of how it is implemented in higher education. This software remains the only comprehensive database with a full range of materials classes and manufacturing processes. It also represents a development towards a systems view of the traditional subject of materials science and engineering with sustainability resources, which adds value to teaching, both for core engineering and design classes.

Keywords—*Materials, Teaching, Sustainability, S-LCA*

I. Visual Property Charts, Design-Driven Approach

The GRANTA EduPack educational software (henceforth *The Software*) [1] was developed as one of the first computer-based materials teaching resources at the Engineering Department of Cambridge University (UK). It consists of two linked databases – one of materials properties (MaterialUniverse) and one of manufacturing processes (ProcessUniverse). These databases contain around 4000 materials and 250 manufacturing processes, respectively, with informative images and schematics to facilitate understanding. This software provides a platform for cross-disciplinary teaching, not only materials-related and manufacturing subjects, but it also supports all types of engineering design and product development courses that includes materials and process selection [2-3] or environmental and sustainability aspects [4-5] of products.

Name	Density	Modulus
	kg/m³	GPa
ABS	1.11e3	1.79
Alumina	3.89e3	366
Aluminum alloys	2.69e3	74.7
Aluminum nitride	3.29e3	324
Bamboo	693	17.3
Borosilicate glass	2.25e3	62.5
Brick	1.83e3	21.2
Butyl rubber (IIR)	910	1.41e-3
Cast iron, ductile (nodular)	7.15e3	172
Cast iron, gray	7.15e3	105
Cellulose polymers (CA)	1.13e3	1.79
CFRP, epoxy matrix	1.55e3	102
Concrete	2.45e3	19.4
Copper alloys	8.94e3	129
Cork	170	25.5e-3
Epoxies	1.25e3	2.69
Ethyl vinyl acetate (EVA)	950	20e-3
Flexible Foam (LD)	51.6	1.73e-3
Flexible Foam (MD)	89.7	6.93e-3
Flexible P Foam (VLD)	23.7	500e-6
GFRP, epoxy matrix	1.86e3	20.5
Gold	19.3e3	79
High carbon steel	7.85e3	207

Name	Density	Modulus
	kg/m³	GPa
Ionomer (I)	945	0.291
Lead alloys	10.7e3	13.7
Leather	922	0.224
Low alloy steel	7.85e3	211
Low carbon steel	7.85e3	207
Magnesium alloys	1.84e3	44.4
Medium carbon steel	7.85e3	208
Natural rubber (NR)	925	1.94e-3
Nickel alloys	8.89e3	204
Paper and cardboard	642	5.17
Phenolics	1.28e3	3.65
Polyamides (Nylons, PA)	1.13e3	2.9
Polycarbonate (PC)	1.17e3	2.21
Polychloroprene	1.24e3	1.18e-3
Polyester	1.21e3	3.02
P-etheretherketone (PEEK)	1.31e3	3.85
Polyethylene (PE)	949	0.746
PE terephthalate	1.34e3	3.38
Polyisoprene rubber (IIR)	935	2.37e-3
Polymethyl methacrylate	1.19e3	2.92
Polyoxymethylene (POM)	1.41e3	3.54
Polypropylene (PP)	900	1.18
Polystyrene (PS)	1.04e3	1.77

Name	Density	Modulus
	kg/m³	GPa
Polytetrafluoroethylene	2.17e3	0.47
Polyurethane	1.13e3	7.75e-3
Polyurethane (tpPUR)	1.18e3	1.65
Polyvinylchloride (tpPVC)	1.43e3	2.98
Rigid Polymer Foam (HD)	283	0.31
Rigid Polymer Foam (LD)	50.2	42.9e-3
Rigid Polymer Foam (MD)	113	0.126
Silica glass	2.19e3	70.9
Silicon	2.32e3	147
Silicon carbide	3.15e3	429
Silicone elastomers (SI, Q)	1.53e3	10e-3
Silver	10.5e3	71
Soda-lime glass	2.46e3	70
Stainless steel	7.85e3	199
Stone	2.28e3	34.6
Tin	7.27e3	43
Titanium alloys	4.6e3	104
Tungsten alloys	18.7e3	343
Tungsten carbides	15.6e3	661
Wood, typical across grain	727	1.22
Wood, typical along grain	693	11
Zinc alloys	5.89e3	80.4

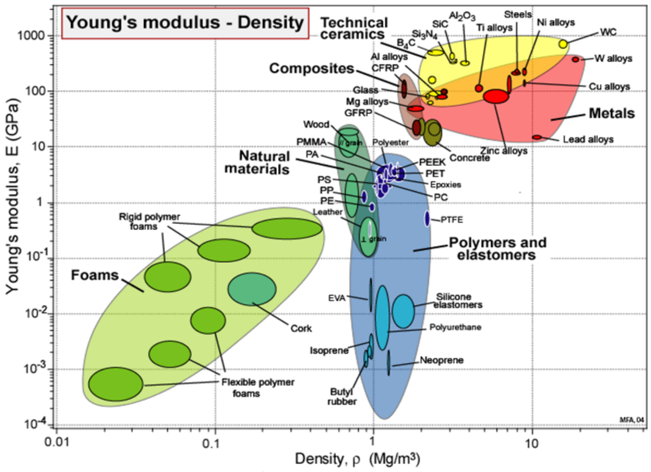

Fig. 1. The traditional way of presenting numerical material property data (top) contrasted with the alternative visual Ashby chart (bottom) [2].

An extensive number of comparable properties are given in individual datasheets. All these properties are possible to represent in colourful charts (Ashby charts) that provide good overviews and a good basis for understanding (in contrast to numerical data formats) while aiding decision-making, see Fig. 1, above.

Traditional Materials Science literature and courses are normally *Science-driven*, whereas this software pioneered a *Design-driven* approach to materials-related teaching (Fig. 2) and is well known for material and process selection within technical design [2-3]. However, it still recognizes the underlying science, for example, through the built-in interactive *Science Notes*, facilitating a more flexible *on-demand* approach to learning.

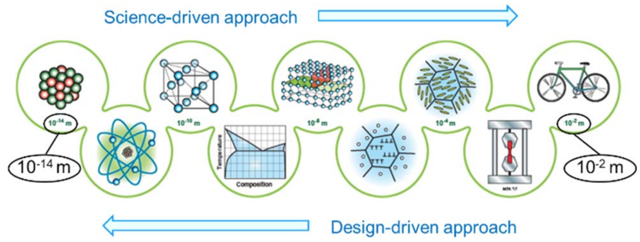

Fig. 2. The schematic difference between a Science-driven approach and a Design-driven teaching approach that is associated with use of Ashby charts.

The visualization tools promote the understanding of the science behind material properties in several ways, see Fig. 3.

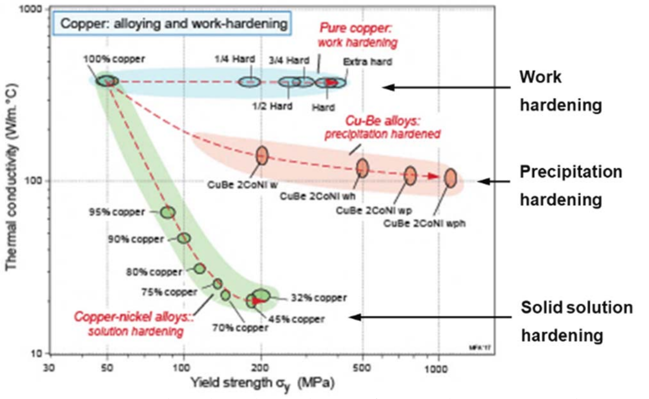

Fig. 3. Trajectory plots show the evolution of material properties with various degrees of hardening processes applied.

The underlying methodologies, tools and databases behind EduPack have over recent years been developed to support both or a combination of the two approaches. In particular, a dedicated database for *Materials Science and Engineering* has specific visual tools to develop the understanding of microstructures and phase diagrams. Another database is focused explicitly on *Design* aspects of products. Both of them retain material and process selection capabilities at the introductory level but represent innovative practises in teaching materials to engineering students.

II. The Introduction of Eco Data and Eco Audit

A. Selecting Materials Based on Eco-Properties

The systematic methodology for materials selection developed by Ashby *et al.* [3] involves the derivation of a performance Index for a material under conditions specific to an application. This index can be used to rank the materials after screening, to find the top-performing ones in an objective manner, using visual charts. Since the materials data contain both price and embodied energy estimates, two objectives in conflict, such as minimizing energy and cost, can be visualized in one chart and trade-offs can be made, see Fig. 4.

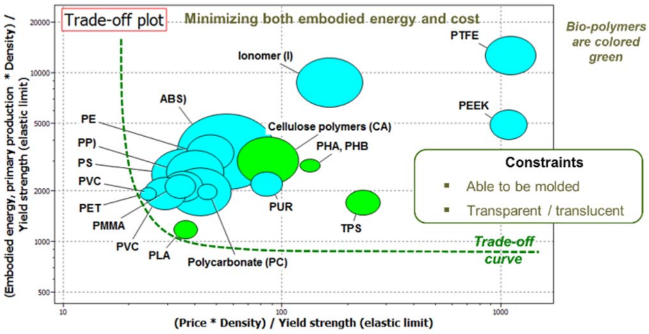

Fig. 4. A trade-off plot generated by the software, for min. energy and cost.

B. A Life-Cycle Tool for Early Stages of Eco-Design

The Eco Audit tool performs a streamlined Life-Cycle Inventory (LCI) of a product to enable designers to assess and compare different scenarios over a whole life-cycle, including recycled feedstock as well as reuse, recycling and incineration at the end-of-life. In one example, taken from an educational cases study, alternatives to a PET bottle as water container is investigated in a life-cycle perspective. The materials in the comparison (see Fig. 5) are Polylactic acid (PLA) polymer, Aluminum and cardboard (TetraPak), neglecting a thin lining.

Container:	PET bottle (0.5 l)	PLA (0.5 l)	Al-can (0.33 l)	TetraPak (0.5 l)
Units for 10 litre [#]	20	20	30	20
Material (bottle+cap)	PET+PP	PLA+PP	Wrought Al non-aged	Cardboard+PP
Mass [g] (bottle+cap)	23+3	30+3	12.5	20+3
Mass [kg] (dummy)	0.5	0.5	0.33	0.5
Recycled [%]	21	0.3	42.5	71.9
Transport [km]	405	188	936 (road)+41 (ship)	1082 (road)+41 (ship)
Source	Armathwaite, UK	South Downs, UK	Perrier, France	Fläming, Germany
Energy [MJ]	105	97	108	79
CO2 [kg/kg]	5.53	6.11	6.95	4.22

Fig. 5. Water containers in a life-cycle comparison of water containers [1].

This results in a summary chart, see Fig. 6, that can be used to discuss and explore alternative material options and design scenarios. Total energy use or carbon footprint as well as a cost estimate can be mapped in this way.

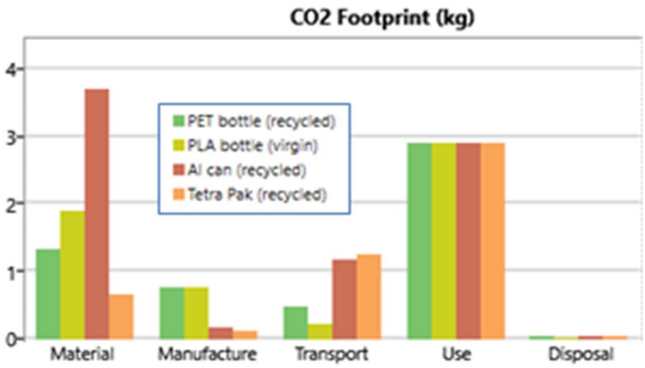

Fig. 6. Summary chart from an Eco Audit of the water containers case study.

III. Environmental and Social Sustainability

During the past two decades, there has been growing pressure to introduce sustainability in higher education. This remains a challenge, as it means a blend of environmental, economic and social concepts need to be introduced in parallel to an already busy core curriculum.

The Eco Audit Tool within the software allows teaching concepts of eco-design covering the product's life-cycle and even includes cost analysis of different scenarios. Sustainable development, however, requires environmental, economic as well as social aspects of sustainability to be considered, sometimes referred to as *the three P:s*; *Planet*, *Profit* and *People*. These can be represented in terms of assets as Natural, Manufactured and Human (Social) Capital, see Fig. 7.

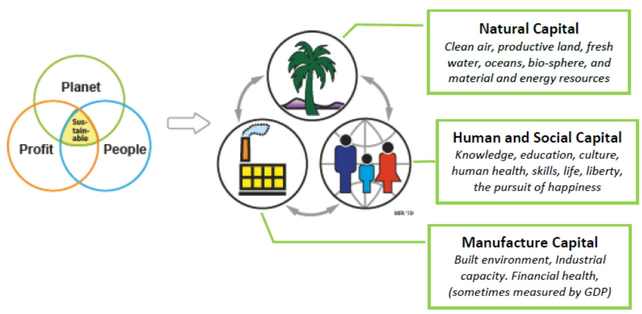

Fig. 7. The three sustainability dimensions and corresponding capitals [5].

An Eco Audit is an approximate environmental account of the material content (feedstock), energy use and carbon footprint associated with a product life-cycle. It is not a complete LCA – it is much less rigorous than that – but quick, easy to perform and useful to indicate the first-order consequences of a redesign of material, logistics, use phase or end-of-life. It is rather a design tool that may be helpful in Life-cycle costing (LCC) since the Audit platform has been extended to include cost estimates for all phases based on the information within the database.

The new EXCEL-based Social Impact Audit Tool (SIAT) offers an introduction to S-LCA methods and thinking. It contains data from the *Nations of the World* data-table of the Sustainability Database [6]. See Fig. 8 for context.

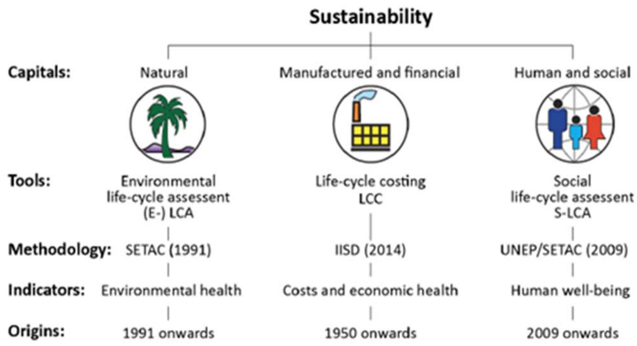

Fig. 8. A comparison between a traditional Life-cycle Assessment (LCA), Life-cycle costing (LCC) and social Life-cycle Assessment (S-LCA) [6].

The Tool maps impact categories, related to each stakeholder group and defined in UNEP/SETAC guidelines [7], with social and economic data about the nations of the world. The main goal of the Tool is to provide an overview of potential social hotspots. These are based on publicly available data, from sources, such as the World Bank, The United Nations and others. The main steps are given in Fig. 9.

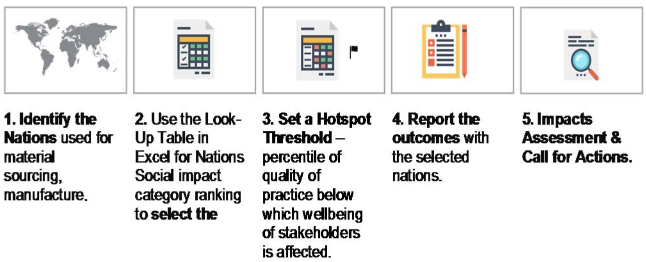

Fig. 9. The implementation of the S-LCA steps using EXCEL-based Social Impact Audit Tool.

The UNEP/SETAC guidelines, which the tool closely follows, identify 31 possible impact categories, which were mapped on the data collected. Table 1 gives an idea of how this mapping works. The full mapping for 5 further stakeholder categories and the data available are described in a white paper [6].

TABLE 1. *Example of mapping impact categories onto available data sources.*

Stakeholder group	Impact category	Mapped to data source
Workers (group 1)	Freedom of association	ITUC Freedom of association
	Child labor	Child labor
	Forced labor	Forced labor and slavery
	Fair salary	Minimum wage
	Working hours	Hours worked per year
	Equal opportunity/Discrimination	Women's share of work force
	Health and safety	Fatal accidents at work
	Social security/Benefits	Social protection expenditure

IV. Summary and Conclusion

In this paper, a software platform has been outlined that has led to innovative novel practices in the area of material selection in engineering and design. It has evolved into a standard tool in materials-related higher education and follows the general development of the subject of materials science and engineering towards a systems-view of materials use in society including global resource aspects. The use of the software for mechanical engineering education has been described and surveyed in student groups [8]. Examples of successfully implemented open source educational resources exist in the form of advanced industrial case studies [9].

This platform has gradually integrated environmental features, such as eco-properties of materials and a streamlined life-cycle investigation tool for eco-design. More recently, an entire sustainability database has been introduced, supporting a sustainability assessment methodology [5]. Examples of how the Eco Audit Tool and Sustainability database are used in undergraduate classes has been published elsewhere [10]. The new Social Impact Audit Tool is a next step and an attempt to introduce a simple visual social life-cycle assessment in relation to products. The SIAT prototype is currently still available for testing [11], while some courses have already provided their feedback. Experiences are presented at the 7th international conference on Social Life Cycle Assessment (June 14-17, 2020, online). Taken together, these innovative components address the sustainability teaching needs at the forefront of higher education.

Acknowledgment

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