SUSTAINABILITY PRINCIPLES PROVIDE A FRAMEWORK TO FACILITATE INTEGRATION OF DESIGN PROCESSES.

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Abstract: Engineers and built environment professionals have been criticized for giving insignificant time to the design phase of projects; architects are considered as designers, leaving the roles of working out details and costs to engineers and surveyors. The advent of ‘Achieving Excellence in Construction’ has led to more integrated approaches, holistic project delivery through procurement, appointment of joint venture multi-discipline consortia and long-term approaches by considering projects across conceptual, design, construction, operation and maintenance phases.

This paper appraises the need for and delivery of an integrated approach by engineers to design, set in the context of sustainability, avoiding a ‘contract designer’ profile and thereby leading to an holistic design process and more sustainable product. Increased understanding of sustainability has allowed higher education students to identify with the connections across several themes such as energy, construction, waste, water, biodiversity and transport, so that a linear approach to design is replaced by integration and feedback evaluative mechanisms.

This sustainability-led design thinking, prompted by UN, UK and RoI drivers, as well as degree accrediting bodies, has been developed with undergraduates at the University of Ulster. The critical encouragement of students to adopt lateral thinking problem solving, learn from successes and failures, apply sustainability measuring systems in design decision-making, consider environmental, social and economic implications simultaneously and re-direct project solutions away form technical answers to the rationale for the project, has inevitably involving radical alternatives.

The paper content is drawn from considerable design teaching experience across engineering disciplines, with input from industrialists, student reviews and external professional body accreditation panels. It demonstrates the benefits of holistic design processes, systems thinking, and adopting a long-term approach to design to ensure that it is an integrative activity.

Keywords: Sustainability; Design; Holistic solutions; Multi-disciplinary projects

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1. INTRODUCTION

1.1 Sustainable Development Context

Strategies, governments, professional bodies, local authorities, environmentalists, non-governmental organisations and a myriad of disciplines have signed up to the concept of Sustainable Development (SD), to the point that the Bruntland definition: ‘development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs’ is widely used, if not fully understood. (WCED, 1987)

The UK Sustainable Development (SD) Strategy further highlights the aspiration ‘to enjoy a better quality of life’ (DEFRA 2005), adding to the complexity of this triple bottom line approach of a balance across Environmental, Economic and Societal elements with four priority areas for immediate action of: Sustainable Consumption and Production; Climate Change and Energy; Natural Resource Protection and Environmental Enhancement and Sustainable Communities; changing behaviour is a key cross cutting theme.

The Irish SD Strategy has similar goals ‘to ensure that economy and society in Ireland can develop to their full potential within a well protected environment, without compromising its quality, and with responsibility towards present and future generations’ (DoE RoI 1997).

1.2 Professional Body Context

Professional Bodies have sought to play a key role in the linking of Sustainability to Engineering. The UK Engineering Council's guidance describes the role of engineers in relation to sustainability. Six principles have been developed, to guide and motivate engineers from many disciplines to achieve sustainable development in their work, and help to meet professional obligations, addressing contribution to a sustainable society; professional and responsible judgements; exceeding legislative norms; resource management, and adopting multiple views to solve problems and managing risk. (Engineering Council 2009).

The Royal Academy of Engineers introduced a ‘Visiting Professor in Engineering Design for Sustainable Development’ Scheme (1999 – 2008), and produced a set of Guiding Principles, identifying the three supporting elements of sustainable design in Fig. 1.

The Institution of Civil Engineers has nine sets of attributes for those who aspire to be professional members and chartered engineers; two are shown in Fig. 2 (ICE3001A, 2009)

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**Fig 1. Engineering Design (Dodds & Venables 2005)**

<table>
<thead>
<tr>
<th>Group</th>
<th>Attribute</th>
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<tbody>
<tr>
<td>Engineering</td>
<td>A Ability to <strong>identify, review and select</strong> techniques, procedures and methods to undertake engineering tasks.</td>
</tr>
<tr>
<td>Application</td>
<td>B Ability to contribute to <strong>design &amp; development</strong> of engineering solutions.</td>
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<td></td>
<td>C Ability to implement <strong>design solutions</strong> and contribute to their evaluation.</td>
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### Sustainable Development

<table>
<thead>
<tr>
<th>Sustainable Development</th>
<th>A Sound knowledge of <strong>sustainable development</strong> best practice.</th>
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<tbody>
<tr>
<td></td>
<td>B Ability to manage engineering activities that <strong>contribute to sustainable development</strong></td>
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**Fig. 2. ICE 3001A (2009) Routes to Membership extract**

1.3 Higher Education Context

Higher Education is being challenged to address SD through several drivers. The UN Decade of Education for Sustainable Development 2005-2014 goals (UNESCO 2003), set challenges for all levels of education. In support, the EDU-COM Conference (2008) recognised that people around the world are experiencing a fundamental transformation towards knowledge-based and knowledge-dependant communities, facilitated by improved information and communication technologies. Higher education for SD is seen as a process of learning how to make decisions that consider the long-term future of the economy, ecology and equity of all communities’ Capacity development is a key task of higher education (Kaen, K 2008).

1.4 Built Environment Context

‘60% of a nation’s fixed capital formation is provided by the built environment industries and professionals’ stated the UK Government Chief Construction Advisor (Morrell P 2010), and therefore contribute to ‘quality of life’. This service operates across all phases of a project.

The Office of Government and Commerce is an independent office of HM Treasury, established to help government deliver best value from spending, and has set key goals for progress: value for money; projects on time, quality and cost; getting best from Government Estate; delivering sustainable procurement and sustainable operations; supporting government policy goals; improving capability in procurement, project and programme management (OGC 2010). These goals have significant relevance to the built environment.

1.5 Design Context

Global concepts are being translated into local applications in the form of Local Agenda 21, as part of the action plan agreed at the 1992 Rio Earth Summit (Agenda 21 1992). This is described as both a process – ‘engaging and empowering the community to influence its own future’ and a product – ‘a better, more sustainable future’. This fresh approach to tackling Local Agenda 21 is replicated in the DETR By-Design Report (By-Design 2000), and at the heart of this report is the ‘need for Engineers and others to ‘work it out for yourself’. The holistic nature of Design is emphasised in the Planning Policy Guidance 1: “good design should be the aim of all those involved in the development process and should be encouraged everywhere”. By-Design uses this approach, for an Urban Design problem, to identify key prompts such as character, continuity and enclosure, quality of the public realm, ease of movement, legibility, adaptability and diversity.

‘Improving quality of life through design’ is the strapline of the Commission for Architecture in the Built Environment’ (CABE 2010), and its work in Design Reviews, publications and as a watchdog body for design across all elements of infrastructure, urban places, buildings and rural development bring immense benefits to society.

Problem solving and awareness of global issues is common to several disciplines. Typical of this universal desire for integration is the non-engineering writing, Futurewise, by economist, medic and Christian writer, Dr Patrick Dixon, in which six faces of global change are identified under the banner of ‘either we take hold of the future or the future will take hold of us’ (Dixon 1998).
1.6 Commentary
This brief review of literature and context-setting to consolidate relationships between SD and Design, indicate their inter-dependence in delivering the built environment, as well as relevance to all engineering disciplines. Higher education has a vital opportunity to contribute to these agenda and support engineers’ development. The diverse sources point to the need for Engineers to take charge of the globe, to preserve the Natural Environment and to be fully equipped for now and the future, operating within relevant ethical standards, primarily in the interaction between the principles of Sustainability and the practice of Design.

2. SUSTAINABLE DEVELOPMENT & DESIGN – COMMON THEMES

2.1 Design Philosophy
The delivery of any built environment project should be seen in the continuum of Feasibility – Design – Construction – Operation – Maintenance – Demolition; hence the design phase is not an exclusive activity, but contributes to the overall sustainability of a project at several stages. Appraisal of SD themes indicates that it is imperative to have design solutions for built environment projects which address issues such as Energy, Transport, Water, Construction, Waste Management, Biodiversity, Project Economics, Social Impact, Environmental Impact, Community Engagement, Materials, and Procurement et al. These SD and design themes can be mapped onto and assessed using a number of SD assessment systems or tools.

At Higher education level, most vocational degrees in the built environment family are required to meet professional accreditation standards which expect SD integration and an ability to address design issues. These challenges have been approached in two distinct ways: a. An elemental product approach, in which elements are designed primarily with best practice in mind; this philistine scientist approach is solely driven by Codes, directed by software packages, evidenced by complex analyses and packaged into a portfolio of contract documents; b. A process approach in which systems thinking is applied at all stages to ensure that sustainability is at the heart of decisions, such that design decisions involve back-tracking and future proofing; this results on integration of systems and disciplines.

2.2 Design Pedagogy
This process approach to design, applied to the teaching of design at undergraduate level for civil engineering and building services engineering students at the University of Ulster for over 10 years, is conceptually shown in Fig 3. and described schematically in Fig 4. The schematic diagram indicated that over 70% of time is spent on the decision making element of the process with the remainder on the detailed ‘product design’ phase. Hence the decision making phase is central and this has been developed through a balance across both ‘banking theory’ and ‘discovery based theory’ of accumulating material.

Fig 3. Conceptual Process Approach to Design at Undergraduate level in UU
NEED
Information Collection & Data Gathering

SOLUTION STRATEGY
Feasible Solutions (3+) wrt. SD, Need, Boundaries, Resources, Impact, Economics + Themes
Evaluation
Optimum Solution Selection
Detailed Design
Calculations Drawings Specification Bill of Quantities Contract

Fig 4. Process Design Approach

The Banking Theory of education assumes that information is acquired and banked or stored up for later recall and application. In context of banking theory, a careful analysis of the teacher-student relationship at any level, inside or outside of education, reveals its fundamentally narrative character. This relationship involves a narrating subject (the lecturer) and patient (the students). The contents, whether values or empirical dimensions of reality, tend to the process of being narrated to become lifeless and petrified. (Friere P 2010).

In contrast the Discovery Based Theory expects students to obtain and appraise information in order to be able to optimize its use and value. In psychology and education, learning is commonly defined as a process that brings together cognitive, emotional, and environmental influences and experiences for acquiring, enhancing, or making changes in one's knowledge, skills, values, and world views (Wikipedia 2010). This approach suits the integrative and multi-discipline requirements of sustainability design.

2.3 Design Programme
Undergraduate degrees, which aspire to provide graduates who have the attributes of a built environment professional body, will have elements of design and SD at all levels of the degree programme – typically: awareness in Year 1; elemental design and SD relevance in Year 2 and detailed multi-disciplinary design and SD concepts in Year 3.

This paper uses the design module and experience of the Year 3 (final year) Design activity in the School of the Built Environment at UU for engineering degrees which operate in the built environment disciplines – civil engineering and energy and building services engineering. Staff facilitates undergraduates to engage in engineering design against a background of SD awareness and single thematic applications (waste, water, transport, etc) so that they can ‘address design challenges from a holistic approach’. Understanding, teaching, leading to facilitating, and directing of this Conceptual Design thrust has given responsibility and opportunity to embrace new approaches and influence graduate thinking and career pathways.

Fig 5 sets out a typical Design lecture, tutorial and workshop programme in 2-hour sessions, along with assessment points, while Fig 6 gives a range of engineering projects which have been used to allow students to develop their SD design capabilities. These projects are
allocated randomly, but have served to give all students a similar design learning experience, and each project is supported by a similar industrially sourced case study.

a. Teaching & Learning by 2 hour Sessions

<table>
<thead>
<tr>
<th>1-2</th>
<th>SD &amp; Design Concepts</th>
<th>3</th>
<th>Learning Theories</th>
<th>4</th>
<th>Decision making systems</th>
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<tbody>
<tr>
<td>5-8</td>
<td>Case Studies from industry</td>
<td>9-12</td>
<td>Group brainstorming</td>
<td>13-16</td>
<td>Group Outputs</td>
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<td>17-18</td>
<td>Group Assessment</td>
<td>19</td>
<td>Individual design</td>
<td>20</td>
<td>Design Review</td>
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</table>

b. Teaching & Learning by 2 hour Sessions

| 3 | ‘Conceptual Design’ task (20%) [Individual] | 16 | Group Poster (20%) [Team] |
| 16 | Individual Interviews by industrialists (15%) [Individual] | 16 | Group Report (25%) [Team] |
| 20 | Individual Design Task (20%) [Individual] |

Fig. 5a. Design Studio timetable; Fig. 5b. Assessment by percentage

<table>
<thead>
<tr>
<th>Municipal Waste Treatment</th>
<th>Airfield Site Development</th>
<th>Waste Landfill Site Development</th>
<th>Railway Route Development</th>
<th>Marina Site &amp; Layout Selection</th>
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<tr>
<td>Energy from Waste</td>
<td>Renewable Energy Development</td>
<td>Water Laboratory Selection</td>
<td>Marina Breakwater Design</td>
<td>Eco Village Development</td>
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<tr>
<td>Sewerage &amp; Flooding Design</td>
<td>Energy from Water</td>
<td>Wind Farm Development</td>
<td>Wastewater Plant</td>
<td>Water Trunk Main Route</td>
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<td>Upland Water Scheme</td>
<td>Rural Sewerage Development</td>
<td>Urban Traffic Congestion</td>
<td>Town Bypass Project</td>
<td>Aquarium Selection</td>
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<td>Sports Museum Design</td>
<td>Transportation Design</td>
<td>Island Infrastructure</td>
<td>Racing Track Development</td>
<td>Off-Shore Wind Generation</td>
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Fig 6 Student Group Project range

2.4 Design Assignment and appraisal

Each assignment serves to develop the deeper SD & design relationship:
Assignment 1: Conceptual study requiring students to develop ‘holistic philosophy’ – typically ‘learning from failures’; ‘design - art or science?’; ‘design behavioural change’; ‘Developing World and Environmental issues’ (Megacities 1995)
Assignment 2: Group Project Poster, allocated randomly, using topics from, Fig. 6 above; assessment by Industrial Panel (IP) of 4-6 senior engineers;
Assignment 3: Individual Interview on Poster content, by IP;
Assignment 4: Group Report (10k words) by IP;
Assignment 5: Individual Design task with unique brief, and costs.

It is evident, from scores, external examiners and SD Visiting Professors, that this design study is both attractive and solicits high student engagement. Appraisal of scores over 10 years, in Fig 7, show that performance has been high, typically 65% average compared to 62% for taught modules, and no failures.

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<tr>
<td>Concept</td>
<td>20%</td>
<td>62.6</td>
<td>67.8</td>
<td>68.1</td>
<td>63.8</td>
<td>63.14</td>
<td>67.5</td>
<td>63.7</td>
<td>70.1</td>
<td>59.6</td>
<td>65.7</td>
<td>58.6</td>
<td>64.6</td>
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<tr>
<td>Poster</td>
<td>20%</td>
<td>63.8</td>
<td>65</td>
<td>65.7</td>
<td>69.5</td>
<td>61.94</td>
<td>62.8</td>
<td>59.5</td>
<td>65.2</td>
<td>64.7</td>
<td>66.7</td>
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<td>Interview</td>
<td>15%</td>
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<td>Report</td>
<td>25%</td>
<td>68.4</td>
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<td>66.17</td>
<td>65.5</td>
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<td>64.7</td>
<td>69.3</td>
<td>66.1</td>
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<td>Design</td>
<td>20%</td>
<td>71.8</td>
<td>63.3</td>
<td>69.6</td>
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<td>66.75</td>
<td>65.2</td>
<td>65.3</td>
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<td>64.4</td>
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Fig. 7 Design Module Performance Average scores over period: 2000 - 2010

Standard deviation evaluation for this period, in Fig 8, also fails to clarify the consistent performance. Observation, student surveys and anecdotal evidence indicate that students
compete aggressively with each other and for honours classification marks, resulting in ‘mark bulking’, as accumulative assessment allows them to re-direct effort and deliver enhanced performance. Similarly, the marking of group work has led to close awareness of individual effort and ability.

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<td>27</td>
<td>19</td>
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<td>6.16</td>
<td>3.82</td>
<td>5.81</td>
<td>6.63</td>
<td>4.03</td>
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<td>3.1</td>
<td>8.56</td>
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<td>Individual</td>
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<td>Poster</td>
<td>20%</td>
<td>5.31</td>
<td>5.11</td>
<td>4.7</td>
<td>3.17</td>
<td>3.93</td>
<td>5.03</td>
<td>3.78</td>
<td>3.03</td>
<td>6.39</td>
<td>3.69</td>
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<td>Team</td>
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<tr>
<td>Interview</td>
<td>15%</td>
<td>5.97</td>
<td>4.1</td>
<td>4.5</td>
<td>3.37</td>
<td>4.6</td>
<td>4.42</td>
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<tr>
<td>Report</td>
<td>25%</td>
<td>4.08</td>
<td>7.12</td>
<td>5.26</td>
<td>3.01</td>
<td>7.93</td>
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<tr>
<td>Design</td>
<td>20%</td>
<td>9.64</td>
<td>4.33</td>
<td>4.62</td>
<td>6.65</td>
<td>6.22</td>
<td>6.91</td>
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<td>4.24</td>
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Fig. 8 Design Module Performance Standard Deviations over period: 2000 - 2010

2.5 Commentary on Design Elements

The following points demonstrate lessons learned from UU and issues to be addressed:

i. **Staff** members are drawn from those who have had experience, both good and bad, in practices, and who are versed in the primary disciplines of Sustainable Engineering (municipal, environmental, civil, infrastructure, building services);

ii. **Industrialists** from 6-10 consulting engineering practices annually deliver live case studies, provide design briefs, act as mentors during group design, assist in assessment of posters and interviews and give formative feedback on Design process;

iii. **Continuing Professional Development** Certificates are awarded to industrialists;

iv. **Conceptual Design Assessment** requires students to appraise multi-discipline ‘what if’ issues and give commentary;


vi. **Decision-Making** is central to the discovery based theory, and this uses the tool of Brainstorming, involving a small group of creative people in idea-generating sessions under controlled conditions. As groups of students approach any problem, the need to reach solutions which meet needs, live within reasonable boundaries, and are defensible give rise to the use of Decision-Making Matrices. Management theory describes this as ‘a system leading to the conscious selection of a course of action from among available alternatives to produce a desired result’ (Meggison 1992);

vii. **Tutoring from Staff** and industrialists embrace the processes and elements of sustainable development & measurement, pre-design planning, risk assessment, environmental impact, emergency planning, decision making, financial, contractual and procurement;

viii. **Case studies** from industry are allocated separately to each group on a random basis and have included liver projects as shown in Fig. 6.

3. SUSTAINABILITY DESIGN APPRAISAL ~ CONCLUSIONS

3.1 Student benefit for a range of communication and assessment techniques; such as sketching, optioneering, optimisation, technical, environmental, financial, teamwork, constructability, conceptual thinking. Student performance is enhanced by a balance of group and individual work. Final summative assessment tends to ‘bulk marks towards to the median score’, due to the accumulative effect of regular formative and diagnostic feedback, student competition for marks and the high level of engagement with the design experience. Not all students favour this conceptual approach, with some preferring taught material.
3.2 Industrial input should be monitored by: a. Academic observation of ‘consistency of approach in case study delivery’, and evaluation of student support; b. Feedback Questionnaires to seek commentary on design processes, student products and potential ‘continuous improvement of Design module’.

3.3 Design teaching must be supported by normal University appraisals

3.4 External Examiner engagement is vital for independent academic review.

3.5 Input and commentary from relevant accreditation bodies (ICE, CIBSE and Energy Institute) brings value and critical observation at all levels.

3.6 External recognition gives currency and credibility; august bodies such as The Royal Academy of Engineering can add value - UU student Group Posters have gained awards.

3.7 External evaluation from leading academics or practitioners is valuable - two UU Visiting Professors have critiqued the entire design processes and outputs

3.8 Continuous improvement can lead to enhanced experiences for all parties, through academic appraisal; an Integrated Design module at post-graduate level has evolved.

3.9 All engineering disciplines can benefit from a systems thinking approach to SD integration.

3.10 The authors acknowledge the support and guidance given by Industrials and other academic staff, external bodies and experts in the delivery of this Design module,

4. REFERENCES


Morrell P (2010) New Civil Engineer 31-03-2010; ‘Now is the time to eliminate waste’


