Day One Sustainability

Emissions reductions targets for the UK set out in the Climate Change Act for the period to 2050 will only be achieved with significant changes to the built environment, which is currently estimated to account for 50% of the UK's carbon emissions.

The socio-technological nature of Civil Engineering means that this field is uniquely placed to lead the UK through such adaptations. This paper discusses the importance of interdisciplinary teaching to produce multi-faceted team approaches to sustainable design solutions.

Methods for measuring success in education are often not fit for purpose, producing good students but poor engineers. Real-world failures to apply sustainable design presents a serious, difficult to detect, and ultimately economically negative situation. Techniques to replace summative examinations are presented and discussed, with the aim of enhancing core technical skills alongside those required for sustainable design.

Finally, the role of our future engineers in policy-making is discussed. In addition to carbon, the provision of water and food will heavily influence the work of civil engineers in the coming decades. Leadership from civil engineers with the technical knowledge and social awareness to tackle these issues will be required. This provides both opportunities and challenges for engineering education in the UK.

Introduction

The built environment has a huge impact on the environmental, economic and social well being of the UK. Research has consistently shown that the between 40 and 60% of UK carbon emissions are associated with activities in the built environment (BIS 2010) with the majority of this (Morrell 2010; King 2010) coming from energy use in buildings.

This paper discusses engineering sustainability from the perspective of teaching and research undertaken at the University of Bath Department of Architecture and Civil Engineering. A blended delivery of building physics, architecture and civil engineering is demonstrated as a key way in which academia can work with industry to provide graduates who have the skills required to meet global challenges beyond 2050.

The importance of instilling sustainability in all teaching from day one is presented and the role of industry, research, material use, and policy are all discussed. Challenges beyond embodied carbon reduction are introduced in the context of future teaching, and the role of assessment in all of these aspects is considered before conclusions are drawn.

The University of Bath

The joint Department of Architecture and Civil Engineering at the University of Bath was formed in 1965, and was led from 1976 by Professor Sir Ted Happold. Its successful approach to teaching engineers and architects together has gathered excellent rankings and student satisfaction in both disciplines.

The Department has an annual intake of approximately 200 undergraduate, 60 post-graduate taught and 20 post-graduate research students. The five undergraduate degree programs (BSc (Hons) Architecture; Master of Architecture; BEng Civil Engineering; MEng Civil Engineering; MEng Civil and Architectural Engineering) all offer placement opportunities.

Interdisciplinary research within the Department is currently focused in three main research groups, the output of each feeding directly into the relevant taught units:

(1) The BRE Centre for Innovative Construction Materials (BRE CICM) has 20 research active staff working in innovative and sustainable construction materials and technologies.
(2) The Centre for Advanced Studies in Architecture (CASA) supports collaborative research amongst architectural history, contemporary design, archaeology, conservation, and emerging digital technologies.
(3) The Energy and the Design of Environments (EDEn) group research lies primarily in the field of sustainable building design and building physics.

Drivers

The Climate Change Act (DECC 2008) sets out binding and ambitious targets for embodied CO_2 emissions reductions (Figure 1). Meeting these targets will require concerted action from many disciplines, with the construction industry being one of the largest potential contributors to future success (Morrell 2010). Given that there are fewer than forty years until the target for an 80% reduction in carbon emissions must be met, providing graduates with the leadership and technical skills required to meet this challenge is essential.

Day one

Giving students both an understanding of the challenges the built environment faces, and tools to measure their impact upon it, is a critical stage in generating a mindset of sustainability. It is crucial that this is encouraged immediately, and new students on all degree programmes are introduced to sustainability on day one of their induction through the 'Carbon Counter' pocketbook (Lynas 2007).

Since we measure what we care about, and that we adjust our behaviour based on the metrics we are measured against (Ariely 2010), the 'carbon counter' is an appropriate first step. The University of Bath also publishes the Inventory of Carbon and Energy (Hammond and Jones 2011), a gold standard in measuring carbon, that is used throughout studio project work.

Providing students with a means by which carbon can be measured, however approximately, enables them to immediately optimise their approach to sustainability and has the potential to impact the way they undertake their personal and professional lives.

Year 1

After induction, the first year of education is crucial. 'Teaching' sustainability in the last semester of final year would be of no practical use, as students would not have had three-years worth of practical experience of making mistakes before they graduate. Such a late introduction could also give the impression 1) that sustainability is not important or 2) that it can be bolted on to a project at the end; neither outcome is particularly helpful in conveying the importance of the subject.

Taught units with assessment directly relevant to sustainability in the undergraduate engineering programs within the Department are summarised in Figure 2, with the unit weighting given to first year clearly evident. Note that credit ratings are under the European Credit Transfer and Accumulation System (ECTS), rather than the Credit Accumulation and Transfer Scheme (CATS).

Building engineering physics

Professor Doug King (visiting Professor at the University of Bath), in a report to the Royal Academy of Engineering (King 2010), suggests that in order to properly address sustainability in the built environment, professionals with a fundamental understanding of building engineering physics are needed to limit energy use while achieving desired levels of environmental performance.

However, building engineering physics is not taught widely within undergraduate degrees in the UK and there are just three MEng degree courses in the UK that are accredited by the Chartered Institute of Building Services Engineers (CIBSE 2013) which meet the Engineering Council requirements for Chartered Status. Additionally, the Joint Board of Moderators (which combines the Institution of Civil Engineers, the Institution of Structural Engineers, the Chartered Institution of Highways and Transportation and the Institute of Highway Engineers to accredit degree programs) requires students of structural engineering to have only an awareness of building physics (JBM 2013) .

Within the Department of Architecture and Civil Engineering, the taught unit 'Built Environment 1', undertaken in the first semester of first year, is dedicated to energy use in buildings, focusing on a fundamental understanding of energy flows and building physics. This is critically important and is therefore undertaken as soon as possible.

The unit allows students to undertake basic physics calculations to inform decisions about building orientation, envelope materiality and construction to achieve a desirable internal environment. This process requires a degree of iteration and demonstration of how design changes influence the internal environment, and subsequent energy use. To supplement this, the students' design repertoire is enhanced through a range of case studies focussing on both best practice and common mistakes.

Assessment and adaptations for sustainability

Within the broader context of a unit focusing on the fundamentals of structural design, coursework is used to investigate how design can influence environmental performance. Every first year student analyses a building on the University of Bath campus by considering the architecture (does the intent work, how is the space used by inhabitants, what is the circulation like); the structure (system used, materials, potential for recycling, evidence of sustainable design); and the building environmental performance (lighting, ventilation, acoustics, thermal comfort). Students must sketch cross-sections and an internal view showing what the building is like to use. They are encouraged to touch radiators, look for mould, comment on the air temperature, and to talk to the building users.

Suddenly structural design is much more than strength and stiffness. The coursework also requires an assessment of the building against modern sustainability criteria. Aside from the newer buildings on the University of Bath campus, most perform badly (much of the campus was built in the 1960s). Finally, suggestions are made as to how the building could be adapted to make it more sustainable and all of this information is presented on a single A3 sheet. Peer review of each student's work in the form of a 'critique' allows the students to learn from each other.

Peer review forms an important part of first year work. This method of assessment helps the students to better understand the importance of good communication in engineering. A Water Tower design project takes up this concept. Working in groups, the students must design a water tower within pre-defined material use constraints. The design packs are then distributed so that each design group builds the structure designed by a different group. The importance of clear communication is then immediately apparent, and each constructing group is able to provide useful feedback to the original design group as they have all undertaken both sides of the process.

Material choices

Measuring carbon can drive the ways in which products are specified and used in construction. However, considering operational efficiency but not embodied energy could result in solutions that perform well in their lifespan, but need replacing often and add significantly to total embodied energy and emissions (Sturgis and Roberts 2010).

As the proportion of whole life energy taken by operational energy in the built environment falls, so the importance of limiting embodied energy rises. Sturgis and Roberts (2010) also conclude that as much as 60% of whole life carbon could be accounted for in embodied energy, and some analyses suggest that by 2050 improved energy efficiency could see 90% of whole life emissions arising from embodied energy (Figure 3).

Material choices, therefore, require consideration of much more than just mechanical properties. Resource depletion and scarcity, carbon, and energy use must also be a part of materials education.

Providing a broad knowledge base of innovative material choices is crucial in this respect. In first year, two-page papers are used as a tool to achieve this. Students must choose a construction material that is not steel, concrete, timber or masonry, and consider current and future uses, carbon credentials and general sustainability issues. They must also, crucially, discuss any opportunities the material presents for carbon reductions. Examples of materials chosen range from rammed earth to cardboard, and from glass to strawbales.

Every student then reads and grades every other paper to provide a process of knowledge sharing and peer review that gives the entire cohort a feel for the possibilities of non-traditional construction materials.

Summary

First year education provides students with a basic vocabulary in structural design, architecture and building engineering physics. This provides the basis for subsequent projects and discussions, makes them aware of the impingements upon the body that can be caused by poor building physics, and introduces them to the principal design variables of the built environment.

Later years

As students progress, the principles that they learnt in first year are reinforced by direct application to project work and supplementary taught units. In Years 2 and 3, building engineering physics is developed within two further units.

Building Environment 2 (Year 2) builds on the passive design methods introduced in in Year 1 by considering the active control of building environments. Heating, ventilation, day lighting, fire suppression, and acoustic systems are all considered. Students are then able to qualitatively and quantitatively assess environmental control systems.

Building Environment 3 (Year 3) provides a practical application of the previous two units. Specific topics include low and zero carbon heating system technologies, assessment of occupant thermal comfort, heating degree-days to estimate energy use and the introduction of Passivhaus design concepts. Alongside these the Department also runs an annual week-long bespoke Passivhaus course for its students, which prepares them for the official Passivhaus examination, should they wish to register for it. The applied nature of Building Environment 3 is specifically intended as preparation for the subsequent design projects and eventual graduate work.

In Year 3 a joint engineer-architect project focuses on reducing material use and constructability, and in Year 4 the ‘Basil Spence Project’ is fundamentally all about creating an holistic design which encompasses architecture, structure and building physics innovation in order to achieve an inspirational low-energy use building.

Materials

Embedding materials into all aspects of teaching allows students to link their material choices to scarcity, carbon, future proofing and reuse. This feeds directly into design projects where carbon counting is used as one tool in the assessment of design decisions, helping to demonstrate the importance of material choices for sustainable design. This is quite different to more conventional materials teaching that may consider only chemical composition, structural properties and financial cost.

Beyond undergraduate programs, post-graduate taught courses must also provide materials teaching. Within the MSc in Civil Engineering: Innovative Structural Materials, topics including advanced timber engineering, fibre reinforced polymers, sustainable concrete technology and glass engineering are introduced.

Both undergraduate and post-graduate courses within the Department are linked to our research activities. This is important for both academics and students and is reinforced at an annual departmental research seminar in which all students are invited to listen to brief research summaries from every academic. This seminar ensures students are introduced to what we are doing in all areas of sustainability.

Research

Research is hugely important for developing taught units and research outcomes are fed directly into taught units. Developing the use of radical, low-carbon building materials and reinforcement technologies to aid decarbonisation of the built environment is the key goal of the BRE Centre for Innovative Construction Materials. Material innovations arising from the centre are strongly embedded in teaching and project work throughout engineering and architectural degree courses.

Increasingly, taught units use computation for design and analysis. The Centre for Advanced Studies in Architecture (CASA) supports this through its research in parametric design and multiple-objective layout optimisation for complex structures. The centre works regularly with industry to apply their knowledge to real problems (Shepherd and Williams 2010), allowing students to see the impact that research can have on their industrial practice.

Research in building physics by the Energy and the Design of the Environment group focuses on extremely low-energy buildings that meet the requirement for an 80% cut in emissions by 2050 and the refurbishment of existing structures – both areas that will be crucially important throughout our students' careers. Alongside this research is undertaken into the future of cities and the way interconnections between people and infrastructure will be important for transforming the efficiency of energy use, creation and distribution within urban areas.

Industry

Given that higher education is the primary route to entry into the engineering profession, strong links must be maintained between industry and academia. A tripartite approach utilising 1) visiting staff, 2) an industrial liaison panel, and 3) our alumni, has been successful within the Department.

The Department employs some 150 visiting tutors each year, all of whom are chosen in part for their sustainability credentials. As a result, students are exposed to leaders in sustainability from both an academic and industrial perspective. This is evidenced by eleven of our visiting Professors and alumni being included in Building Design Magazine's Top 50 Green Leaders (Gilbert 2012).

An industrial liaison panel made up of forty members from across the UK provides input on all aspects of teaching and research programs undertaken within the Department. This input is crucial and must be timely – changes made to a first year degree course in 2013 will only be seen in the graduates of 2016/17.

From these links with industry our students are quickly encouraged to form a sustainability mindset in their first year of study. They begin to understand that, at least initially, they will not be judged by the mistakes that they make, and that making mistakes is crucial for learning and is far better than not trying at all. Learning from these mistakes and disseminating best practice is a key tool for sustainability in the built environment.

The success of our teaching program is reflected in the achievements of our graduates. Graduate Kai Qu (2010) was named the Institution of Structural Engineers Young Engineer of the year in 2013 (IStructE 2013), several of our alumni sit on the Council of the Institution of Structural Engineers, and 2008 graduate Oliver Neve won the Institution of Civil Engineers Graduate and Student Papers Competition in 2012. Other alumni successes include the IStructE Supreme Award for Structural Engineering in 2011 for the Olympic Velodrome, the award for sports or leisure structures, the David Alsop Award for sustainability, and the Heritage Award for Building or Infrastructure Projects (IStructE 2011).

Beyond Carbon

Carbon, water and food form the cornerstones of our sustainability agenda in both research and teaching. Each of these aspects is covered in our current teaching portfolio, with relative importance changing as new funding and research centres are launched.

Water

Averaged over a global population, there is sufficient fresh water on the globe for everyone's future needs (UN 2013), yet such a simplification overlooks the problem of regional water scarcity that affect billions of people (UN 2012). Changes in water policy, and management in food production, will be required to meet growing demands for water resources.

Civil Engineers are well versed in the demands of managing and moving water, giving them the ability to shape global access to water. The technology to do this is available; getting it into practice will be a question of policy making and political will.

Investment in a water quality laboratory is the first step in a new program of research in this field. A dedicated, newly built laboratory within the Department is due to launch in 2014, with this infrastructure investment being matched by funding for new research staff positions. A second collaborative project worth £2.5M between the Department of Chemical Engineering and Wessex Water Ltd to set up a 'Water Innovation and Research Centre' will be launched in 2014. The centre will provide a unique environment to conduct water technology and resource management research, and civil engineering academics will be involved.

This research, along with inter-departmental collaborations will lead to the changes to teaching that are required to meet our sustainability challenges to 2050.

Food

Global populations rising towards 9 billion by 2050 (Chamie 2004), coupled with changing and increasingly rich diets, is driving up demand for food. Some estimates suggest that the increase in demand could exceed 50% by 2030 (Zoellick 2008).

Global food production could, however, provide everyone with a high calorie diet – global food production could already provide upwards of 2700 calories per person per day (FAO 2002). Yet this is not the case as food is wasted, people cannot afford it, or it is badly distributed.

Simply ensuring that global farmers reach their production potential, which would require no new technologies, could provide a 50% increase in yields (Foley et al. 2011), making the problem of food provision primarily one of management and not science.

Civil engineers have the capacity to lead in this area, where policy, coupled with political and social stability, is key. The management of land has analogies with the management of construction projects, where resources are balanced with cost over time to ensure the desired end result is achieved. These skills are taught across the curriculum in 'Construction Management' and are transferrable into wider fields, such as food and land management.

Stronger regulation and government policy is required in many countries to provide a global food network with robustness against economic events and climate change. Increasing food prices has been closely linked with civil unrest after the food crises of 2008 and 2010 (Bellemare 2012).

Although the period 2050-2080 may not be as productive as 1950-1980 (Fraser 2013), this does not necessarily imply that food will be more scarce than it is today. Rather, a change in the way that food is dealt with will be required. Having the solutions means that policy makers need support to make the decisions that are necessary.

With research in carbon and water well underway, the next big issue for Civil Engineers will be in food. This is fundamentally a Civil Engineering problem, as seen in work by Norton and Lane (2012) and Shrivastava (2003). Its solution will come from land management and international government policy, informed by the research-led teaching in food, water and waste management of our future Civil Engineers.

Policy

Both food and water, the big global issues after carbon, require strong leadership and management to implement many of the technological revolutions that have been available for some decades.

Within hydraulics, our teaching already includes water management policy as a core topic. Understanding global differences in water policy is crucial if the challenges outlined above are to be met.

However, weak political structures can mean that decisions are never made, or that money is wasted on projects that do not provide long-term benefits. Many decisions ultimately have little to do with money, and more to do with weak leadership in policy making that means decisions are not made (because no-one has the support or knowledge to make the decision).

These challenges are demonstrated in Tanzania, where despite water resources of 2300m^3 per capita (Frenken 2005) widespread water scarcity exists due to low water storage capacity, variations in rainfall distribution and intensity, and institutional weaknesses in water management (MKUKUTA 2007).

This makes the provision of water and construction management education crucial. Students are shown how important it is to get involved in policy-making decisions; and this means that they must become leaders.

Assessment

Assessing engineering degrees can lead to contradictions in practice. Students are judged by exam results, but examinations are not what an engineer does. Industrial feedback suggests that on occasion first class students show less skill in industrial settings than some with a third class degree. Such a situation simply shows that degree classifications can measure the wrong thing.

Assessment by closed book examination is one means by which this situation can arise as such exams often take the form of a memory test rather than assessing fundamental understanding. This is pertinent in structural analysis, where a full understanding of the principles adds coherence to subsequent calculations (May and Johnson 2008) and avoids surface learning effects.

Examinations themselves have also changed, with questions now designed to test an ability to think in a qualitative way being desirable. More traditional mathematical assessment can then be undertaken as coursework, which better represents the reality of engineering practice.

The future may see examinations becoming the background, rather than front-line, assessment. This is illustrated in Figure 4 where a proposed unit assessment route is shown. Assessment by short individual or group projects and workshops (1 hour to 1 day in length) inserted throughout the semester would allow students to demonstrate their working and practical knowledge of a subject. Assessment of up to 80% of the unit marks in this way would then be supported by a final examination focusing on their ability to think around key topics. The key to this approach is that the examination would have to be passed to progress, but the weighting given to it would be appropriately low.

It is envisaged that such an approach would generate engagement (through workshop sessions) and a more philosophical outlook of graduates. Under this model of assessment, a student awarded a first class degree would (it is hoped) graduate as a first class engineer capable of an holistic approach to sustainable design.

Support

The extra-curricular endeavours of students must be supported at all stages. Providing opportunities and financial support to explore ideas is key to this. Since 1998 The Happold Trust has supported a travel scholarship for one or two final year students. Modest financial support (£1000) has achieved great things and provided real benefits to our graduating students.

Recent projects include:

- 2013 – When the Levee Breaks: Dealing with the aftermath of storms in the USA (Jack Ford)
- 2012 – Structural contradictions in the UAE: from essential to extravagant (Roseanne Boyce and Elizabeth Smith)
- 2011 – Engineering the Trans-Siberian railway, and seismic design in Japan (Matthew Bouloux)
- 2010 – Construction of mountain refuges in the Pyrenees (Robert Foster)

Engineers Without Borders has a strong program of activities within the Department. Students who undertake these opportunities tend to learn more than they provide to the people they visit and this is a key reason why support is provided.

Conclusions

This paper has shown how a blended delivery of engineering, architecture, building physics and the freedom to experiment can provide a basis for sustainable design in the built environment. Introducing a way of thinking in first year that is then reinforced in subsequent teaching and project work has been key to the success of this approach at Bath.

This approach is not the only (or necessarily the best) way to approach teaching engineering sustainability. Our annual reviews of teaching mean that the course content is able to change quickly, if needed. This paper does not presume to suggest that we have done everything right, but aims to demonstrate the success we have achieved with the methods we have used. It should act as a discussion point for engineering education.

A current emphasis on building environmental physics is set to increase in the future and this should be common across all civil engineering degrees. More universities need to get building physicists involved in their teaching and research, with the possibility for future MEng level degree programs in Building Engineering Physics as a third strand to the ‘classic’ architecture and civil engineering programs.

Design for use and post occupancy need to be considered more in practice, and this means taught design units must include these issues. This should be matched with appropriate examination techniques that assess students’ ability to think rather than to do sums.

It is clear that academia and industry have a lot to learn from each other and the role of our industrial liaison panel has been important in developing the degree program that is run today.

The importance of legislation in all of this, associated with sustainability is key to achieving change in the built environment and will be driven forwards through education.

Finally, all of these aspects have been achieved whilst retaining 100% positive student feedback across all graduate program areas (HEFCE 2012). Challenging and motivating students with high quality teaching and assessment methods is key to continuing this.

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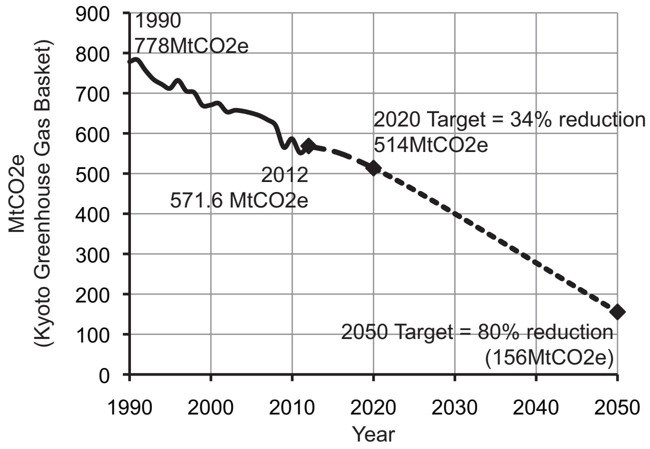

Figure 1. Targets for emissions reductions in the UK (DECC 2008)

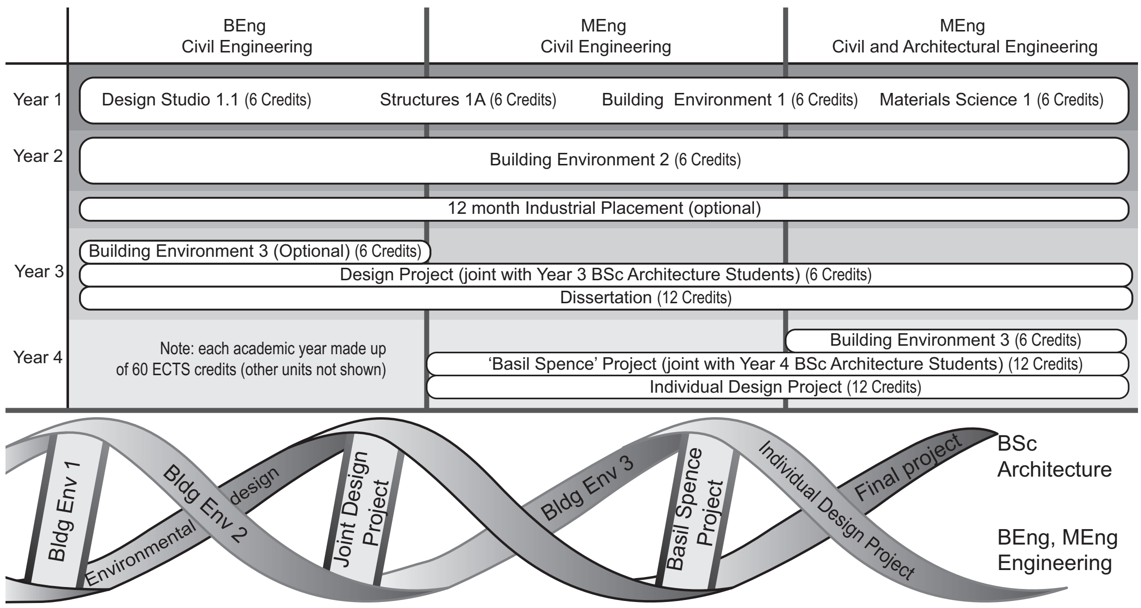

Figure 2. Degree program overview, relevant units only (top) and links between Architecture and Engineering units (bottom, after King (2010))

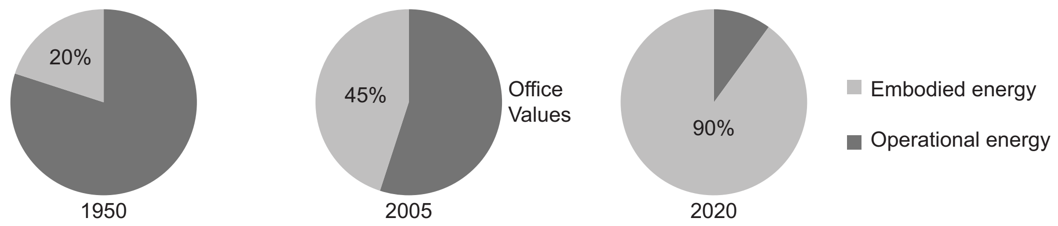

Figure 3. Embodied energy versus Operational energy use from 1950-2050 (after Lane (2007) and Sturgis and Roberts (2010))

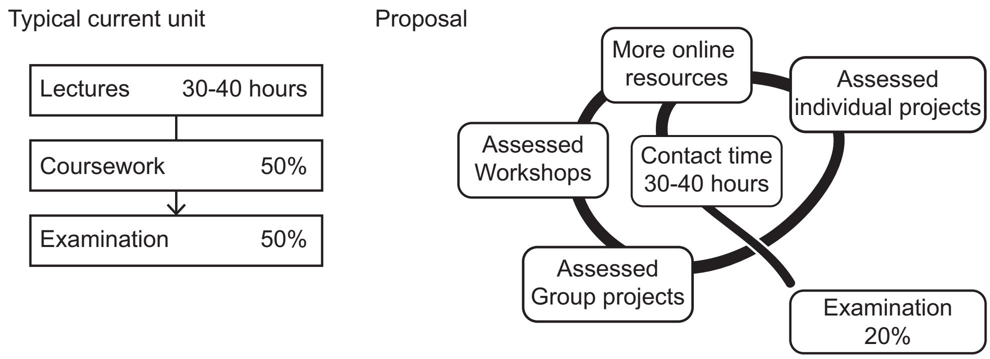

Figure 4. A new model for assessment