THE CHALLENGE OF LEARNING CONCEPTUAL DESIGN OF SUSTAINABLE CONCRETE-FRAMED BUILDINGS AT UNIVERSITIES ICCS13 CONFERENCE PROCEEDINGS

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ABSTRACT:

The challenge of learning conceptual design at universities is exacerbated with the introduction of sustainability that is a relatively new and fast evolving subject. The legislation-driven carbon agenda has accelerated the process and the industry is developing solutions to address this agenda. However these solutions are not always available to universities. In this paper the current practice of conceptual design of sustainable concrete-framed buildings is reviewed, the contribution of structural engineers to holistic building design is explored, future research and development issues are noted and initiatives to improve teaching and learning of conceptual design are proposed.

Keywords: learning, conceptual design, sustainable, concrete-framed buildings, universities

1. PRACTICE

Conceptual design is the starting point of all projects. General concepts and ideas are generated from a range of known possible solutions. The design team carries out an appraisal of each alternative solution by considering all relevant design constraints and selects a limited number of solutions to be carried forward to the preliminary design stage.

Decisions taken during the conceptual design stage of a project are likely to have more significant impact on the total cost and construction programme of the project – see Fig 1 – as well as the project's sustainability credentials. It is therefore essential that these crucial decisions at conceptual design stage are appropriately informed with latest research and development of materials – usually generated by academia – and state-of-the-art design methods & innovations in construction techniques – normally developed by industry.

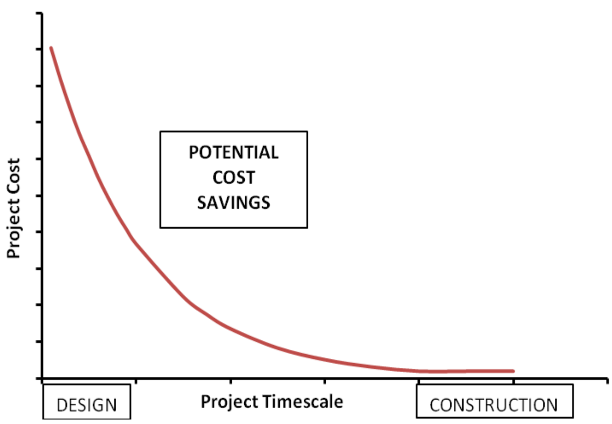

Fig 1: Potential cost savings over time of the project

Achieving sustainable buildings is not just about choosing sustainable materials in construction. Structural engineers in practice spend a disproportionate amount of time in choosing materials to minimise impacts such as embodied carbon although the embodied energy used by a building is only 10-20% of its total life cycle energy - the rest being operational energy [1]. Perhaps in the future when renewable energy sources and clever energy conservation systems are further developed and widely used the embodied energy will become a more significant criterion in conceptual design. In the meantime a sustainable building can only be achieved by minimising its operational energy. Structural engineers are not normally involved in energy design and usually have limited training and understanding of energy issues.

A concrete-framed building can be designed to be more sustainable firstly through the 'right' client brief that ensures the right scope, purpose, size and location and secondly, the design team will deliver the most sustainable design by optimising the balance between minimising impacts and maximising performance. Strategic decisions at this earliest stage – 'stage A' or appraisal stage of RIBA Outline Plan of Work [2] - will inevitably have the greatest influence on how sustainable the final project is or not. Structural engineers are not always involved at stage A of a project.

At stage B or design brief stage the building life span, parameters for climate adaptation and key requirements such as functionality are decided. If the future function is pre-determined e.g. transforming the Athletes Olympic Village of London 2012 Olympic Games into long term residences then it becomes part of the client brief. If functional requirements are completely unknown, the structural engineer delivers flexibility by considering issues beyond the constraints of intended first use such as different imposed loads, variable column spacing / floor spans, changing floor to ceiling height, deflection or vibration limits, provision of voids / extension, amended services, allowance for climate adaptation, etc. For example designing foundations for future use is quite critical in big cities such as London where the cost of removing deep foundations of old buildings to build new ones can be a major issue. There is obviously an increased cost for increasing flexibility so ‘judgement’ must be exercised on how much to invest for an unknown future. There is limited guidance available in this area of increasing importance although ‘not compromising future generations’ is a key sustainability requirement.

Ideally a building should remain functional for a very long time to better utilise building material resources. However buildings will become a lot more energy efficient in the future and the question is ‘when is it best to demolish an existing high operational energy building and replace it with a low operational energy building?’ Furthermore, in new building design, ‘should it be expected that a building will be replaced by a more energy efficient one before the structure needs to be replaced?’ To address such questions structural engineers have to apply a whole life thinking approach to design looking at various future scenarios of variable impacts such as embodied / operational energy / CO_2. The latter is only one of the environmental impacts and for simplicity’s sake, other parameters such as efficient use of resources or disruptions to communities are rarely incorporated at this stage. A simple example of whole life thinking is shown below – Tables 1, 2 & 3 – where the simplistic conclusion appears to be that 2X30year lifetime scenario is arguably a more sustainable solution than the 1X60year lifetime scenario. Are decisions taken on that basis and how informed are they?

Table 1: Indicative Embodied Carbon Values

Indicative Embodied Carbon Values (kg CO_2 e/m^2 of gross internal area)		
New build (shell and core)	500	(60 yr life)
Fit-out (Cat A)[Note 1]	200	(60 yr life)
Fit-out (Cat B)[Note 2]	100	(every 7.5 years)
New Build Total	800	
Minor Refurbishment (incl. Fit-out Cat B)	150	(every 15 years)
Major Refurbishment	500	(every 30 years)
Demolition and Disposal	50	
Annual Operating Energy Emissions (now)	90	
Annual Operating Energy Emissions (in 30 years time)	60[Note 3]	

Table 2: Example for 60year lifetime scenario

	Embodied	Operational	Total
New Build	800	60yearX90	
Fit-out (Cat B)	100		
Minor Refurbishment	150		
Fit-out (Cat B)	100		
Major Refurbishment	500		
2 x Fit-out (Cat B)+ Minor Refurbishment	350		
Demolish	50		
Total	2050	5400	**7450**

Table 3: Example of 2X30year lifetime scenario

	New Build	Fit-out (Cat B)	Minor Refurbishment	Fit-out (Cat B)	Demolish	Total
Embodied 0 to 30yrs	800	100	150	100	50	1200
Embodied 30yrs to 60yrs	800	100	150	100	50	1200
Operational 0 to 30yrs	30yrs x 90					2700
Operational 30yrs to 60yrs	30yrs x60					1800
Total =						**6900**

NOTES:

1. *Fit-out (Cat A): There is no standard definition for category A fit-out – it can vary between owners / developers. Typically, category A is what the developer provides as part of the rentable office space and usually comprises raised floors, floor coverings, suspended ceilings, extension of the mechanical and electrical services above the ceiling from the risers, finishes to the internal face of the external and core walls, window blinds*
2. *Fit-out (Cat B): The fit-out to the occupier’s / users specific requirements. It can typically comprise installation of cellular offices, enhanced finishes, conference/ meeting room facilities, reception area, enhanced services / specialist lighting, IT & AV installations, tea point/ kitchen fit-out, furniture*
3. *It is assumed that operational energy of buildings in 30 years time will be a lot less (60) that the operational energy of today’s buildings (90)*

Nevertheless how accurately CO_2 emissions are measured and accounted in the decision making process? Jowitt et al [3] questions the simple expedient of transforming carbon emissions into costs and then including them as part of the usual whole-life costs and cost-benefit analysis and, outlines the requirements and principles for a protocol for carbon accounting for infrastructure projects. Whilst research in this area is on-going, grey areas in decision making process still remain and structural engineers are expected to use the good old 'engineering judgement'. But is engineering judgement reliable in sustainability? Measuring sustainability has proved to be a challenge for structural engineers as it requires them to translate a problem defined by complexity science to a solution delivered by Newtonian science [4]

In this challenging climate where research and innovation are moving hand in hand with professional practice, clients are more demanding requiring holistic solutions where the whole design team of architects, building physicists and structural engineers are integrated right from the start of a project. Other drivers for holistic design include innovations such as renewable energy and technology such as Building Information Modelling (BIM) that will become compulsory for publically procured projects in the UK from 2016. The whole design team must now be involved in every decision, for example choosing exposed concrete requires an architect who appreciates the aesthetics as well as the concrete's acoustic and lighting performance, a building physicist (e.g. mechanical & electrical engineer) who understands energy and applies the benefits of thermal mass and a structural engineer who can provide 'lean' solutions perhaps by choosing post-tensioning to minimise the floor thickness and consequently the height and weight of the building. Do structural engineers have the necessary skills and competencies in order to practice in this challenging climate? The Institution of Structural Engineers envisages that its members should be able not only to practice sustainable structural engineering but also to lead the design teams in the future. So learning conceptual design of sustainable concrete-framed buildings is of paramount importance for both education (universities) and training (industry). But how well is it done at universities? Before this question is answered it's worth looking at research that underpins learning at universities.

2. RESEARCH

Research funding for traditional structural engineering subjects has been declining in the last decade with sustainability increasingly been favoured by UK and European funding councils. However, given the diverse and wide nature of the sustainability umbrella, one could potentially classify any project as a sustainability one. Some research in structural engineering has been successfully funded under sustainability headings. Current and future research in concrete normally covers areas such as modern structural design solutions using non-linear analysis techniques; material innovations such as High Performance Fibre Reinforced Concrete, FRP reinforcement, Self Compacting Concrete; probabilistic approach to verification of durability, more durable concrete mixes; code improvements such as punching shear of flat slabs, crack width evaluation, refined prediction of deflection; and sustainability credentials such as thermal mass and reducing embodied CO_2. Research findings from all these areas normally find their way into design standards and regulations that are used in conceptual design.

However a more fulsome approach is required whereby integrated through-life data is made available to the structural engineer in considering future scenarios and the structural engineer is trained in applying whole-life thinking. There is so much to gain from so doing: on one typically sized non-domestic building, through careful consideration, a structural engineer could save their lifetime's personal carbon footprint [5]. Life Cycle Assessment (LCA) is hardly used in construction although it is a well established tool in other industries. LCA can help assess environmental impacts but its integration into design / asset management strategies and reliability over long lifecycles are limited. New research and tools are needed to integrate dynamic LCA techniques in conceptual design and support decision making practices.

3. LEARNING

Teaching and learning of conceptual design at universities is a challenge. The 20th century pedagogical methodologies in teaching design i.e. "learning by doing", "learning by exploring" and "learning by reflection" are well known, tested and used. Technology has further enhanced learning with on-line tools such as the EU funded R&D project called WINDS i.e. Web-based INtelligent Design tutoring System in support of the learner-centred Virtual University [6]. Nevertheless both established methodologies and modern techniques are usually hindered by several basic shortcomings such as insufficient resources (e.g. not real life projects and case studies with actual solutions), inexperienced tutors (e.g. academics with limited structural design experience) and inadequate curricula (e.g. programmes not providing appropriate emphasis, not offering enough time and not using an effective delivery for example learning in design studios as architects do). These three shortcomings are discussed below:

- A number of universities in the UK have developed excellent relationships with the construction industry i.e. local consultants, contractors and clients. This is also driven by a requirement from the Joint Board of Moderators (JBM) - the accreditation body of civil engineering degrees in the UK - that departments have to establish an Industrial Advisory Board with the remit to assist them in developing and implementing their strategies for teaching and research. Industrial members of the Board normally deliver guest lectures and support academic staff in delivering an up-to-date curriculum enhanced with real life projects. Nevertheless the quantity and quality of the Board's contribution varies depending on local availability of expertise and resources constraints. Material bodies in the UK such as The Concrete Centre have contributed greatly with resources in support of conceptual design however their only concern has traditionally been the specifying engineer and not the student. There is therefore a need for student-centred resources for learning conceptual design of concrete-framed buildings.

- Lecturers of structural engineering at universities are mostly research driven with limited industrial experience especially in structural design. Although there have been initiatives to change that, such as the scheme by the Royal Academy of Engineering that sponsors young lecturers to spend time out in the industry, the situation is not getting any better. The industry in the UK has observed that a large number of graduates do not understand structural behaviour and this has further been verified by the particularly poor results in the Chartered Membership Exam of the Institution of Structural Engineers in recent years. As a result, the Institution has made the issue of 'appropriate lecturers for teaching structural design' the theme of the Academics Conference in 2012.

- Civil engineering curricula are packed with diverse subjects as required by tradition and accreditation bodies. It is virtually impossible at times for students to find enough time to explore and reflect on what they do. This is quite detrimental in learning conceptual design. Engineering students are normally taught in classes of large numbers using traditional lectures and tutorials. This is not always the most effective way of learning. There have been brave initiatives to change and improve learning of design. For example a university has combined lectures and tutorials to 'lectorials' and introduced on-line formative assessment and, another university reduced all the formative assessments in the first year to one big project incorporating all learning outcomes where students work in teams – simulating practice – and lecturers are their consultants. But what happens at the other 53 civil engineering departments in the UK? And why all departments of architecture get it right by teaching conceptual design in studios?

Sustainability has made teaching and learning of conceptual design at universities even more challenging as it is a relatively new and fast evolving subject. In the UK, it was initiated by the Royal Academy of Engineering in 1998 with the operation of a Scheme of Visiting Professors in Engineering Design for Sustainable Development at a number of Universities. The principal aim of the Scheme was to assist – across all engineering teaching, not just design – in the generation of teaching materials for the undergraduate curriculum based on real-life case studies, and to enhance the understanding of sustainability amongst academic staff and students alike. As a result, a set of guiding principles on teaching sustainable development for academic staff was published in 2005 [7]. The Engineering Council incorporated sustainable development competences in its UK Standard for Professional Engineering Competences in 2004 followed by the Joint Board of Moderators requirement that sustainability is integrated into existing teaching and learning curricula running as a thread through the programmes of all accredited civil / structural engineering degrees [8]. However there is evidence to suggest that a number of universities have just introduced the subject by incorporating sustainability modules into their curricula rather and effectively embedding sustainability in all subjects.

The concept of sustainability is still evolving but the carbon agenda has accelerated the process as there is a legislative driver (80% reduction in CO_2 emissions by 2050 in the UK) and industry is addressing that agenda now. This has led to a recent revision of JBM guidelines asking universities to produce graduates who are not only familiar with the concept of low carbon but also have the ability to use carbon criteria to make decisions i.e. carbon accounting. The challenge is that industry guidelines do not currently exist and the only relevant work on the subject is carried out in practice.

4. RECOMMENDATIONS

Sustainability is informed by research and driven by practice. Students of civil / structural engineering courses normally have good access to research findings but they are not always exposed to latest developments in design & construction and are not necessarily taught by practicing engineers. These shortcomings make learning of conceptual design of sustainable concrete framed buildings a challenge. Universities have to work with the industry to ensure that resources such as on-line conceptual design guides and expertise either from industry or by training lecturers of structures are developed for the benefit of students.

A good example of e-resources been made available by the industry is CALcrete that is a comprehensive suite of 16 e-learning modules (over 200h) for concrete materials, design and construction. It is offered free to all students of civil structural engineering degree courses in the UK. CALcrete is continuously updated (e.g. Eurocodes) and enhanced (e.g. global index and navigation to improve learner strengthened quality). A module on conceptual design of sustainable concrete framed buildings should be developed in the future. Other initiatives taken by the concrete industry in the UK to raises competence in conceptual design include an annual student design competition, a programme of guest lectures by industry experts and a biannual concrete communication conference that brings professional practice and universities together in concrete design [9].

Academics normally argue that universities should concentrate in educating students i.e. teaching them how to think rather than training students i.e. teaching them how to use a particular design code, the latter being done by the industry. Hence educating students about sustainability, it's making sure that students learn how to think in a sustainable way. But in most cases academics concentrate in delivering their own subject expertise and ignore whole life thinking. It's absolutely imperative that academics review their teaching & assessment resources and strategies to embed sustainability into their subject including conceptual design.

Professional bodies have a significant role to play too. In response to industry concerns about the level of understanding of structural behaviour, the Institution of Structural Engineers started an education project to address these concerns in September 2010. Driven by collaboration and innovation the project is already supporting universities in teaching structural design with initiatives such as an ideal syllabus for structural analysis / design, a web forum for academics, a portal for student resources, innovative technical content, textbooks, an award scheme for teaching excellence and training the trainers activities [10]. There is no doubt that the education project supports learning of conceptual design with concrete and other construction materials.

At UK universities, LCA is researched but not generally taught. As a result graduate structural engineers do not have the skills to employ LCA within decision making and the use of LCA inevitably becomes the sole domain of environmental / energy specialists. But LCA is absolutely crucial in conceptual design. Universities should work together with the concrete industry to commission LCA studies and introduce LCA into civil / structural engineering curricula.

Structural engineers have to be able to understand and work together with architects and building physicists in practice. Students have to learn conceptual design in a similar type of environment i.e. simulated multidisciplinary studio work. To achieve this would require dedicated academics and additional resources provided by universities.

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