

A New Degree Programme in Structural Engineering and Architecture

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Abstract- *Structural Engineers and Architects are educated completely independently. Although both play a major part in designing and building a nation's infrastructure, they are not encouraged to fully understand the work of each other which can result in a lack of collaboration and co-operation, often to the detriment of a project. This divide between the professions is thought by many to start at higher education level. Recently the departments of Civil and Structural Engineering, and Architecture at the University of Sheffield, UK, have introduced an innovative course designed to help remove the barriers between the professions. The four year undergraduate masters degree in Structural Engineering and Architecture is unique in providing graduates with a single degree suitable as a common first step in the professional training for a career in either structural engineering or architecture. This paper outlines the reasons for the introduction of this course, its aims and objectives, and details the modular structure. By careful consideration of the overlaps inherent in engineering and architecture courses (eg structures, materials, structural design etc) it has been possible to combine the structural engineering aspects of an engineering degree and architectural studies into a single degree programme. Thus far the course has been successful in attracting students with excellent high school qualifications who wish to follow a course which allows them to combine design flair and creativity with analytical rigour. The first co-hort of students are now in the third year of the programme. A discussion of the problems they have encountered and the strategies used to overcome them is also included.*

Introduction: The two professions - Architecture and Engineering in the past and at present

Division of the responsibility for the design and construction of the built environment between two

professions - architecture and engineering - is a relatively modern development. Up until about 150 years ago, a single individual performed the roles of Engineer and Architect for the design of a building or bridge. This was not due to the simplicity of the historical designs, some of which, medieval Cathedrals for example, were complex and intricate designs. And yet Cathedrals were designed by 'master builders' who, although they were not architects or engineers in the late twentieth century sense, were able to design very sophisticated structural systems that successfully combined structural adequacy with the creation of beautiful spaces. It might be argued that the so called 'master builders' learnt by trial and error and that they would use a certain concept after learning from their mistakes; a luxury not afforded modern day engineers or architects. Nonetheless there is ample evidence that they were able to appreciate proportions and choose the correct ratios which would produce safe structures and also create beautiful spaces. Concepts such as the flying butress, used to provide lateral stability, showed an advanced understanding of masonry structural systems. The split between the professions coincided to some extent with the formalisation of structural design methodology i.e. producing efficient structures (in terms of both capital cost and construction time) was no longer possible without detailed knowledge of the new materials developed during the Industrial Revolution¹ (steel, r.c.) and new structural analysis techniques, hence the emergence of the Structural Engineer as a separate specialist. This split has become even more entrenched over the last century.

Today all but the simplest of buildings are designed by a team of architects rather than an individual. Often, because of the complexity of the problem, the teams are multi-disciplinary and consist of a number of other professionals: structural engineers, landscape architects, planners, environmental scientists, services engineers, quantity surveyors etc. who work closely together to produce the complete design of a building. The work of

each professional is inextricably linked to that of the fellow professionals and it is therefore vitally important that there is good collaboration and team work.

Perhaps the greatest interaction takes place in aspects of structural engineering and architecture. When producing a good building or structural design both the structural issues and architectural concerns issues must be addressed with knowledge and skill. Because of the very different nature of these fields, and particularly the different ways the two professions are taught, it is not always easy to do achieve the harmony required. Engineers are normally educated to understand how structures work in order to be able to design them. They are taught to understand load paths and conduct detailed calculations to "design" structures. In contrast, architects design buildings with many other issues in mind, of which the structure which enables it to stand is only one. Therefore, architects are taught to understand and deal with structural design at a conceptual level only (afterall an engineer will deal with this for them) and consequently may not be too concerned with providing the most direct load paths. As they are not educated to deal with detailed design of structural section they may fail to appreciate fully the structural implications of their conceptual designs. Frequently it is the aesthetics and context in which the structure should fit that concerns the architect. One of the benefits of the dual course discussed herein is that the students' structural engineering education is just as detailed as the that of mainstream Civil and Structural Engineering students.

The need for a new course

At present Structural Engineers and Architects are educated completely independently. Although both play a major part in designing and building a nation's infrastructure, they are not encouraged to fully understand the work of each other resulting in a lack of collaboration and co-operation, often to the detriment of a project. This divide between the professions is thought by many to start at higher education level, although it may be considered to start even earlier² when secondary school students are required to choose between the arts or sciences. On entering the workforce graduates may soon fall into their stereotype roles.

Looking at historical masterpieces in Architecture, and also at contemporary landmark structures and buildings, the advantage of interdisciplinary educated professionals who understand both aspects of construction (architecture and structural engineering) becomes apparent. In contemporary architecture the most imaginative solutions are usually achieved by a team in which there was a close relationship between the engineer and architect or by one

person who combined the role of architect and engineer for the project, Frei Otto and Calatrava for example.

Billington³ discussed the two extremes of the private house, the design of which is dominated by the utilisation of space and needs no Engineer, and the major bridge, the design of which is dominated by the structural form and needs no Architect. Even if one accepts that analysis, few in the world of building operate at these extremes. The reality in the majority of cases is that the Structural Engineer and Architect must work in harmony if a project is to be successful. Yet, through their education, training and culture, they are often different creatures. Burke⁴ for example, in a recent paper on the aesthetics of bridge design has berated structural engineers for too often being soulless technicians:

"Apparently, their myopic focus on first – cost economy reveals that they have not yet learned that, while the monetary cost of beauty may at times be expensive, the physiological, psychological, social and cultural costs of ugliness are immeasurable."

On the other hand those who endeavour to understand both architectural/aesthetic issues and engineering complexity, for example the Spanish architect and engineer Santiago Calatrava, are sometimes criticised⁵ for embellishing the engineering:

"..He is enough of an engineer to know what he is doing with the flow of force, but he is often perverse in adding structural members which have no purpose except a decorative one."

This dichotomy is the source of many conflicts in the field of building design. The famous cases of conflict are legendary, but mistakes and problems occur at the Architect/Structural Engineer interface on the most mundane building schemes.

A number of UK Universities have attempted to reconcile these differences by introducing Degree courses that are predominantly in one of the two disciplines, but which include some modules from the other. Such courses have made valuable contributions in introducing students to the role of their future collaborators, but practical considerations mean that the student is not fully immersed in both cultures. Further, the graduates from these courses will be qualified to join only the profession in which they majored.

It is for this reason that recently the departments of Civil and Structural Engineering, and Architecture at the University of Sheffield, UK, have introduced an innovative course designed to help remove the barriers between the professions. The four year undergraduate masters degree in Structural Engineering and Architecture is unique in

providing graduates with a single degree suitable as a common first step in the professional training for a career in either structural engineering or architecture. The Royal Institute of British Architects and the Institution of Structural Engineers have both indicated their willingness to recognise the qualification.

Architectural and Engineering Education in the UK

Students wishing to study at a UK university apply through the Universities and Colleges Admissions Service (UCAS). A recent interrogation of the UCAS website⁶ revealed a total of 270 civil and/or structural engineering related courses available at BEng and MEng level at 60 institutions. Architecture related degrees numbered 90 (excluding interior design and landscape architecture) available at 59 institutions. However, a search for courses which combine both architecture and engineering revealed only 26 courses at 12 institutions, and the majority of these were civil engineering with architecture or architectural engineering with the expressed aim of producing engineering graduates with the skills needed to work alongside architects in multidisciplinary teams. Only the Structural Engineering and Architecture course at Sheffield aims to produce graduates who may go on to become either an architect or engineer - the remainder have sought accreditation from just one branch of the profession, usually the Institution of Structural Engineers.

Before the introduction of any new course a case has to be made and approval sought from the Academic Development Committee (which reports to Senate, the chief academic body of the University). Approval was sought in May 1994. At that time a survey of UCAS applications showed that a significant percentage of applicants had an interest in both architecture and engineering. Of those applying to Sheffield at the time, 15% had applied for architectural engineering/civil engineering with architecture courses and a further 9% had applied to read architecture alone. Since launching the course the number of applications has grown steadily. At the time of writing, the number of applications had reached 67 (10% of the total applying to read civil engineering related courses at Sheffield), an increase of 22% on the previous year. The academic standard of the entrants to the course is also high. In the 1996 intake, the 14 students admitted had an average A level score of 26.7 (which compares well with the year average for all civil engineering related courses at Sheffield of 22.8) with five achieving the maximum 30 points. In 1997 the number was 11, with an average of 25.4 (year average 22.6). The standard comfortably exceeds the advertised 24 points required for entry and illustrates that some very good students can be attracted to an engineering

course, which traditionally in the UK have struggled to attract the best candidates. In 1996 for example the average student admitted to a civil engineering course through the UCAS system had a points score of 18.7, about the average for all courses in all subject areas offered in the UK.

The University of Sheffield introduced fully modular degrees in the academic year 1994/95. Students are required to take courses (known as modules) totalling 120 credits per academic year. Each module is typically valued at 10 credits, but 20 or 30 credit modules are also taken in some subjects. Typically a student takes six 10 credit modules in each 15 week semester, 12 weeks of which are devoted to teaching and three to assessment. It was the introduction of the modular system of undergraduate degrees which provided the mechanisms necessary for the implementation of a dual degree.

Combining a three year architecture course and a three year engineering course into a single four year degree programme would appear to present difficulties in completing the necessary content in the time available. However, two factors are evident in the existing courses which assist in the achievement of this aim. Firstly, architecture and engineering courses share a considerable overlap in subject material - for example, materials, drawing, surveying, construction management, structures - all of which need only be covered once. Secondly, in both courses there are areas where a choice in the subjects to be studied is open to the student and are therefore not considered essential to a designer at the architect/engineer interface. The dual course therefore combines the essentials of an architecture course and a structural engineering course principally aimed at buildings and structures. The areas which are excluded are urban and landscape design in architecture, and hydraulics and water treatment (which are civil engineering subjects) from the engineering side.

Table 1 presents an outline of the course structure. The subjects have been arranged under a number of headings, with architectural subjects to the left and engineering subjects to the right. Each block represents a 10 credit unit - double blocks are rated at 20. Thus, in year 1 students take six courses per semester to make up the required 120 credits for the year. Each year is a mix of architectural and engineering subjects. Although it would have been logistically much easier for students to undertake alternate years of engineering and architecture this was considered undesirable so the course instead allows the parallel development of architectural and engineering skills in an integrated manner. The balance between the disciplines varies from year to year but the studio work provides a focus for integrating the two. In year 4, in addition to the courses shown, students are offered a number of optional courses to make up the requisite credits. These options enable students to tailor the final year in the direction which best suits their career aspirations. In engineering for

example, students could choose from courses including Mathematics, Advanced Structural analysis, Structural Dynamics, Stability of Plates and Frames, Solar and Wind Energy. As the course matures it is intended to add other modules which will be of particular interest to dual students, such as long span structures, tension structures and structural glazing etc.

Project work is an essential element of an architectural degree. Therefore students on the dual course spend a considerable amount of time working in the studio on project work along side main stream architecture students. Each and every student is allocated with a space and drawing board in the studio. The main aim is to have these students integrated as much as possible with architecture students. Therefore in group projects dual students are never placed in separate groups, but always in mixed groups with architects. As architecture by its very nature is a sophisticated mixture of art and science, throughout the course different skills are being developed carefully. In the early days of the course a number of workshops are organised where students are taught model making, sketching, life drawing, drawing perspectives, use of CAD, role playing and presentation skills. Dual students follow a programme of studio work derived from the main architectural degree programme but, where appropriate additional emphasis may be focused on the structural aspects. In this way students develop their architectural skills without losing sight of the engineering required to make a scheme viable. In the beginning of the course, especially in the first year this inhibits the students to a certain extent. Their engineering knowledge is not sufficient for them to design imaginative structures. At the same time however, because of their education in engineering, they are aware of the importance of choosing an appropriate structure for their design. They expect of themselves (and are often unreasonably expected) to be able to bridge and join together structural efficiency and aesthetic values in a holistic approach to design. This is not at all an easy task, even for experienced practitioners. Therefore it is not surprising that they struggle to achieve that in the beginning of their course. As they progress further in the course they become better. Looking at the work done by the third year dual students it is evident that they are able to apply with success their knowledge from engineering to their architectural design.

The key to the success of the course is that students are completely immersed in the culture of each discipline. They are taught engineering alongside fellow engineering students in an engineering department by engineering academics. They are taught architecture with architecture students by architects. In this way the students are not exposed to diluted structural analysis and design courses as taught in architectural degrees, nor are they taught simplified design specially adapted for engineers. By

exposure to both disciplines, the students learn to really understand the thought processes and approaches encouraged and developed in each discipline, which are at times surprisingly different.

Challenges

As with many a good idea the problems have been encountered at the implementation stage! A particular problem at Sheffield is the relative location of the two departments. The Architecture Department is housed on the top floors of a 20 storey building 500m away from the home of Civil and Structural Engineering Department. Students have to cross two busy roads to get from one to the other. In the first year of the course this caused a number of problems, with students required to move between locations a number of times in a single day. It soon became apparent that this was impractical and changes to timetables were implemented to limit the movement between buildings by scheduling complete mornings and afternoons in each department. This has proved particularly difficult to achieve as the course has developed because students take modules from a number of levels in each year. For example in year 2, the Humanities courses are level 2 (that is taken by year 2 architects), but the Science and Technology courses are level 1; Structural Analysis and Mathematics are level 2 engineering but Geotechnical Materials is level 1. Thus a change of lecture time to suit the dual students may cause problems for a large body of other students and not always just in one year. Add to this the availability of staff and location of the lecture theatre and the logistics become very difficult. In order to make the timetable work a willingness to change and adapt has been necessary on both sides and the patience and ingenuity of those involved in time tabling tested to the full! In the beginning of every semester the dual students are issued with a detailed weekly time table which states explicitly where they should be every day of the semester. This has proven to be useful because the number of tutorial hours in architecture changes weekly depending on the size and complexity of the project work.

An important practical step has been the allocation of a member of staff in each department to the role of co-ordinator for the dual course, and links between the departments. Regular meetings are held between the two tutors and the dual students at which problems (and plaudits!) can be aired.

A further problem which has arisen occasionally is a failure by tutors to recognise that the dual students are not present in all activities undertaken by a year group. Departments at Sheffield are new to the modular system. For many years all students on a particular degree followed a prescribed set of courses so overlap between lecture

courses, tutorials, project work and assessment presented few problems. However, with the modular system it is important that staff recognise that not all students are following the same programme of study and care is needed that essential material for a module, perhaps forming a part of the assessment, is not subcontracted to another module not taken by all students.

Another problem is the very different culture in the two departments. In Engineering there often is one correct or optimal answer to a set problem but in Architecture a multiplicity of solutions may exist; it is true that some solutions may be better than others but all may be valid. Because dual students are exposed to both cultures at the same time it is often hard for them (especially in the early days of their course) to accept that there may be more than one acceptable solution to a problem and that they have to develop designs that are the most suitable (functional, aesthetically pleasing, in context, etc.) for the set project.

The difference in cultures is also reflected in the students' marks. Concern is expressed that for the same amount of work in engineering (where it is possible to get 100%) higher marks can be achieved than in Architecture. The problem is not that the dual students get lower marks than the main stream architecture students - this is not the case - rather that they are exposed and educated in both disciplines at the same time and therefore are able to contrast and compare the different approaches to assessment in each discipline. There is no simple solution to this problem but perhaps this is one of the most important strengths of the course and not its weakness. Being exposed to the two very different sides of the course and being able to understand and appreciate these differences should help the students understand each other better. Being able to communicate successfully will help them work in multidisciplinary teams and create superior buildings and structures.

Conclusions

The division of architecture and engineering into two distinct professions is relatively new. As most modern buildings and structures are highly complex they require a multidisciplinary design approach combining the specialist skills of engineers, architects and others. Successful designs are invariably the result of either a genuine team effort or the work of an individual capable of combining architectural/aesthetic issues and engineering complexity. However, education of the two professions in isolation leads to a lack of mutual understanding and difficulty in communication.

The University of Sheffield has introduced a new course in Structural Engineering and Architecture which enables undergraduates to be taught engineering and

architecture simultaneously. The key to the success of the course is that students are completely immersed in the culture of each discipline. They are taught engineering alongside fellow engineering students in an engineering department by engineering academics. They are taught architecture with architecture students by architects.

On graduation these students will have the opportunity to become

- an engineer with understanding of and respect for architectural/aesthetic issues
- an architect with the ability to implement structural engineering knowledge in architectural designs
- managers of multidisciplinary design teams, drawing on the undergraduate experience of working successfully in both disciplines
- or even an engineer-architect!

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Acknowledgements

The development and introduction of the Structural Engineering and Architecture course has been an interdepartmental initiative. A number of people have been closely involved. The authors are pleased to acknowledge the contributions made by Dr Roger Harper and Professor Roger Plank in the planning and implementation of the course. Timetabling the course has been particularly taxing and the patience and ingenuity of Dr Allan Craven and Mr Dai Thompson in compiling a workable timetable is gratefully acknowledged. Finally, all staff involved in teaching the dual students are thanked for accommodating the changes in their modules required for the successful implementation of the course.

Architecture					
Year		Humanities	Science & Technology	Project Design & Technology	Communication & Management
1	Autumn	ARC153 History & Theory		ARC155 Studio Projects	CIV182 Drawing
	Spring	ARC154 History & Theory		ARC155 Studio Projects	CIV142 Surveying
2	Autumn	ARC253 History & Theory	ARC177 Science & Technology	ARC155 Studio Projects	
	Spring	ARC254 History & Theory	ARC178 Science & Technology	ARC155 Studio Projects	
3	Autumn	ARC353 History & Theory	ARC277 Science & Technology	ARC155 Studio Projects	
	Spring	ARC354 History & Theory	ARC278 Science & Technology	ARC155 Studio Projects	
4	Autumn		ARC377 Science & Technology	ARC155 Studio Projects	CIV271 Construction Management
	Spring		ARC378 Science & Technology	ARC155 Studio Projects	CIV372 Construction Management

Structural Engineering						
Year		Materials	Structural Analysis	Geotechnics	Maths	Structural Design
1	Autumn	CIV162 Concrete	CIV113 Structural Mechanics		AMA143 Maths & Computing	
	Spring	CIV161 Metals	CIV113 Structural Mechanics		AMA144 Maths & Computing	
2	Autumn		CIV213 Elastic Analysis		AMA252 Engineering Maths	CIV221 Design of RC Structures
	Spring	CIV151 Geotechnical Materials	CIV 214 Plastic Analysis			CIV222 Design of Steel Structures
3	Autumn			CIV252 Geotechnical Properties		CIV323 Advanced Structural Design
	Spring			CIV253 Geotechnical Properties		CIV325 Prestressed Concrete Design
4	Autumn			CIV354 Geotechnical Design		
	Spring			CIV355 Foundation Design		

Table 1 Course Structure

Notes:

Columns indicate a developing sequence of course subjects

Single box represents 10 credit course - double box is equivalent to 20 credits

History & Theory and Science & Technology courses are parts of modules taught as core components of the main BA (Hons) Architectural Studies course

Mathematics and Engineering courses are core components of Civil and Structural Engineering degree programmes.