The Institution of Structural Engineers
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Presented to teams responsible for developing learning/teaching of structural behaviour

First-year design – the design of experimental structures

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Introduction

The early development of design skills is important for undergraduate students in structural engineering, as it provides an integrated context for their other studies and generates interest and excitement in the subject. It is equally important that students are given the freedom to experiment and generate unique design outputs so that they can start to understand their own design identity and develop good engineering judgement. This has been the focus of publications such as that by Stratford[1]. This paper describes an innovative and integrated approach to the teaching of structural design to first-year Civil Engineering students at the University of Southampton, which has received The Institution of Structural Engineers Excellence in Structural Engineering Education Award 2018.

The majority of the first-year Civil Engineering design curriculum is taught via a project called Prototype. Prototype encourages the development of design skills, processes and responsibilities, and challenges the students to develop and prototype structures in response to specific briefs. Focus is placed upon design being an iterative process, the application of fundamental structural understandings, the value of integrating prototyping, and the need for structural engineering to be appreciated as a craft that can balance and homogenise wide-ranging design factors and that can be delivered with ambition, technical skill, subtlety and joy.

This paper describes the design rationale and linkages to mechanics, structures and materials. Wider design activities within the Faculty of Engineering and the Environment, including recent strategic investments, are also discussed. Emphasis is placed on project outcomes.

Excellence in Structural Engineering Education Award 2018

Winner:
First-year design – the design of experimental structures
Alastair McDonald, University of Southampton, UK

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Emerging technologies for a dynamic learning (... while learning dynamics)
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Three applications of augmented reality technologies in structural engineering education
Gareth Whittleston, Jonathan Haynes and Alan Mardan, University of Salford, UK

Programme context and structure

Civil Engineering programmes in a first-year course reorganisation in 2012/13 included three modules: FEEG1002 (Mechanics, Structures and Materials), FEEG1003 (Thermofluids) and Math1054 (Mathematics for Engineers). A revised module CENV1026 (Design and Computing for Civil Engineers), with increased design activity and computer programming, and a new module CENV1027 (Engineering Fundamentals), with basic chemistry and geology for engineers and construction management associated with the Constructionarium activity[2], were included. These changes provide students access to new skills in design and computing, without reducing the content of core engineering science. The development of the first-year modules delivered across the full academic year removed the need for Semester 1 examinations, allowing an intensive two-week design workshop to be run.

2016/17 saw the implementation of the Faculty Approach Transformative Assessment (FATA), which directs a move towards programme-focused assessment rather than module-focused assessment. This has increased the opportunity for students to receive formative feedback with the overall aim of providing greater freedom to develop independence, self-direct, and improve the quality of their learning. Design teaching is integral to this initiative.

A clear sequential design thread exists within the Civil Engineering programmes with project-based modules in each year of study, as recommended by the Joint Board of Moderators (JBM)[3]. Overall, summative design assessment for MEng students accounts for approx. 20% of their degree classification. A key focus within the development of the design curriculum has been to increase its integration with engineering science content throughout the programmes in an exciting and creative way. The activities described in this paper have demonstrated that holistic design can be taught effectively early in an engineering degree programme.

Materials and structures curriculum thread

The first 10 weeks of FEEG1002 Mechanics, Structures and Materials are taught as common content across all engineering disciplines; basic structural analysis of beams, trusses and elastic struts is introduced, along with an introduction to solid mechanics and stress analysis of beams (bending and shear). Civil Engineering students follow their own

Prototype
Traverse
Your brief is to design and make a prototype structure that:
- Responds to the action word above.
- Is unique to, and responds to, your site (its location and its characteristics). The yellow box above highlights the site focus.
- Is designed to suit a person who is 1:20th the scale of you.
- Is easy and safe to install and take down.
- Has a design that is influenced by its materials and its fabrication purpose.

Your prototype is to be tested on site but should not damage the site in any way (the site should be left in the same condition as you find it).

Figure 1
Example brief for Prototype project

discipline within FEEG1002 for the remainder of the academic year.

Further analytical techniques, including the principles of superposition and compatibility, virtual work, rigid body mechanics and arch analysis are taught in CENV1026 Design and Computing for Civil Engineers to ensure that at the start of the Prototype design project, students can analyse common structural forms – beams, trusses and arches – and have a theoretical understanding of stability, determinacy and redundancy.

These two modules underpin the theoretical knowledge of materials and structures and support the design initiative.

The Mechanics, Structures and Materials course continues in Semester 2 (in parallel with the studio-based Prototype project) and covers stress analysis of beams in more depth (e.g. combined loads, unsymmetrical sections, longitudinal shear, composite beams, deflection) plus stresses due to torsion. As these topics are covered, the practical aspects of their application relevant to the Prototype project are highlighted. Examples are the most efficient cross-section shape for beams in bending, the benefits of prestressing on beam performance, shear connection between components of a composite beam, the very different performance of open- and closed-member cross-sections in torsion, and standard formulae for deflections in cantilevers and beams.

The module concludes with an introduction to plastic analysis of beams and frames (including a laboratory experiment in the plastic collapse of a portal frame), and qualitative elastic analysis of beams and frames. Thus, FEEG1002 is a classical first-year 'strength of materials' course with an emphasis on structural element performance, but which takes advantage of the opportunities to highlight its practical application in design.

"PROTOTYPE ENCOURAGES THE DEVELOPMENT OF DESIGN SKILLS"

A distinctive aspect of the materials and structures curriculum is formal lectures in module CENV1026 that address the connection between theory and practice, in both individual element and structural behaviour. These set out a framework for the selection of structural form and material, which can then be applied in the Prototype project. These lectures start midway through Semester 1 and cover loading, load paths, overall structural stability, common structural elements and structural systems. The application of analysis techniques learned in FEEG1002 to practical structures includes the influence of connection type and choice of material. Conceptual design and internal structural stability, and structural dynamics (vibration and resonance, movable and deployable structures) are emphasised. These lectures conclude before the commencement of Prototype, and provide a 'toolkit' of ideas and concepts for the students. Reinforcement of these is aided by the presence of a structures tutor at design workshop sessions.

First-year design curriculum

The Prototype design project is connected to a series of design-related first-year activities. These comprise:

Induction week design challenge

In academic calendar Week 1, students are given a design challenge to design and build a structure that spans a set distance using the limited materials supplied and within a set timeframe. Student groups of five have four defined time periods to develop a range of design concepts, review, test and refine a final prototype. Hand sketching and scale modelling are strongly encouraged throughout. This activity is predominantly an icebreaker exercise but provides an early appreciation of the core skills and abilities needed in an effective design process.

Autodesk AutoCAD and Inventor self-paced learning

Throughout Semester 1, first-year Civil Engineering students use an online self-paced course to learn the fundamental operations and capabilities of Autodesk AutoCAD and Autodesk Inventor. A number of built-in exercises allow the students to test their ability. The Prototype project requires the use of computer-aided design (CAD) to record site survey information, develop designs and to communicate final proposals to industry standards.

MAKE_

MAKE_ is an exercise undertaken by all first-year students throughout Semester 1 that adds further value to the introduction of our design workshops and studio facilities. Each student manufactures and assembles a simple, multi-part component that requires: CAD software to produce drawings for laser cutting parts, the use of the bandsaw and pillar drill to produce components/parts, and cutting threads on a steel rod.

Figure 2 Student groups installing and presenting structures during final presentation

Prototype design project

The Prototype design project runs from Week 17 to 29 and was first delivered within the Civil Engineering undergraduate curriculum during the 2013/14 academic year. The project forms part of the module CENV1026 Design and Computing for Civil Engineers. The following headings describe the key elements and processes.

Project brief

The project brief (Figure 1) is intentionally succinct and open to interpretation and requires the design and prototyping of a structure for a given site. Each group (typically three or four students) is given a different action word (structural task) within a common brief. The brief is formed of three key elements: the site, an action word, and specific design brief criteria.

Site

'Is unique to, and responds to, your site (its location and its characteristics). The yellow box above highlights the site focus.'

Each student group is randomly assigned a site located within the University of Southampton, Highfield Campus. The site is highlighted by a yellow-shaded transparent rectangle overlaid on a photograph of the proposed site (Fig. 1). The shaded area is intended to be the primary focus for locating the structure, but intentionally avoids the use of a defined site boundary. This is to encourage students to consider the wider surrounding context of their sites, challenge and interpret the scope of the client brief and thereby fulfil the lead design role.

Action word

Each brief and associated site has a key action word associated with it – *Traverse, Ascend/Descend* or *Lookout* – and the design of the prototype structure must respond to this word. These words have been chosen to encourage the development of structural concepts, and understanding that structures are carrying out actions (they are not passive), that they have purpose, direction and character. They are also intentionally open to interpretation – there are many ways to traverse a gap.

These words also seek to move away from preconceived ideas of what a structure might be; in particular, what it might look like, i.e. traverse = bridge, ascend/descend = stair/ladder, and lookout = tower. Such thinking often leads to proposed designs looking like famous built structures rather than being unique to the design brief set. Also, there is generally an inbuilt mind-set that the word 'design' relates to visual appearance and that the wackier the form, the better the design.

Fundamentally, this is because the students are not used to looking analytically at the world around them, interpreting what they see and understanding underlying design drivers. This project aims to realise design solutions that result in simple, elegant and highly refined structures, whose appearance is a result of the overlapping factors of context, material, structural behaviour, form, function, manufacturing and the imprint of the designer's hand.

Specific design brief criteria

'Is designed to suit a person who is 1:20th the scale of you.'

The process of interpreting the site and proposed structure at a reduced scale highlights the need to consider the precise details, the narrative and poise of the structure on site, and introduces the importance of considering the interaction of the client/ultimate user with the structure once installed. It also encourages students to consider the length, proportion and cross-sectional dimensions of structural elements.

'Is easy and safe to install and take down.'

The groups are given limited time to install their structure (5–10 minutes) and this criterion highlights the need to consider the safe and easy process of installation from design concept through to detailed realisation. Student groups are required to carry out a risk assessment and write a method statement related to the deployment of their structures.

'Has a design that is influenced by its materials and its fabrication process.'

This reinforces the connection between material characteristics, performance, associated methods of fabrication and their structural characteristics, and a design output. Students are required to fully specify materials based on the required structural performance of the proposed design, available budgets and manufacturing processes.

'Can be tested on site but should not damage the site in any way (the site should be left in the same condition as you find it).'

This criterion has a particularly big impact on the proposed designs that isn't initially appreciated by the students. It requires careful consideration related to the global stability of the structure and the method by which its load is transferred to the site surfaces. The external location of the sites means that they can be exposed to considerable wind loading. The use of the inherent structural mass, stability and the friction generated between the structure and its site becomes vital.

Site survey, process and output

In Week 17, students are required to extensively survey their sites, to closely observe and analyse them and to accurately record quantitative and qualitative information. Key aspects are the broad context of the site, its use and related occupancy, materials, texture and construction, sounds, smell, light (sunlight and artificial), visibility, dimensions, level and geometry. Detailed site information is recorded by hand in sketch books and translated into scaled, hand-drawn technical drawings in the design studio. These drawings form the basis for making accurate, scale, site models and together inform the development of initial project concepts.

Design process
The design process continues throughout the duration of the project. The brief requires students to rapidly define the wider parameters and understand the constraints posed by the physical location through data collection and synthesis. Physical measurements and hand sketches support the construction of simple models to allow the testing of ideas and more detailed structural consideration derived from the free body and force diagrams. Design is an interactive process and regular (weekly) tutorial support allows robust questioning of ideas and judgements and seeks justification of proposals. Gaps and inconsistencies, structural deficiencies and timidity are challenged, and further refinements identified to improve the design.

Weekly tutoring and intermediate review
An intermediate review in Week 21 takes the form of the weekly tutorials described above, but acts as a significant design milestone marking the last point when materials can be ordered from external sources. Design proposals that are underdeveloped and cannot justify the additional expense of ordering additional material are required to use materials readily available within the design studios for the delivery of the prototype structure. This milestone encourages early design development through presenting a significant opportunity for investment rather than needing to be a specific assessment point.

Risk assessment
Students are required to consider the health and safety consequences and risks associated with their proposed structure at key stages – feasibility, manufacture and construction, operation and deconstruction using common semi-quantitative risk ranking and risk mitigation processes and detailed method statements. This has added an important additional reflective input to the design process.

Final project outputs and assessment
The final project outputs that student groups are required to produce are set out below:

"DETAILED SITE INFORMATION IS RECORDED BY HAND IN SKETCH BOOKS"

The assessment of this module focuses on your designed output; the information and decisions that have influenced your design, and the way in which you have communicated your design to others.

You are to ensure that your project reaches an appropriate level of development and coordination and that it is explored and represented in suitable final drawings, models, diagrams and images. It should be presented on a maximum of eight A3 landscape presentation boards. The following list confirms the minimum presentation board content requirements:

- *A brief written description of your design with emphasis on structural performance (try to discuss in a concise way most, if not all, of the important points mentioned above).*
- *Site survey drawings and observations (plans, elevations, sections, views and relevant details [technical and hand sketch] and annotated photographs.*
- *A site Plan and Section showing your proposal and the wider site context.*
- *Your design process and influences (initial concepts, concept development, prototype development and design precedents).*
- *A Plan, Section and Elevation drawing annotated with relevant alignments, dimensions, geometries, setting out information, and relevant context.*
- *A three-dimensional drawing view or views presented in a manner that communicates your design to an external audience. E.g. A three-dimensional exploded/ transparent view, highlighting specific parts or systems and their relationship with the site context.*
- *Annotated drawings to explain the structural, material and construction proposals.*

Specific structural analysis should be:

- *Draw the load path diagram on a 3D view of your design (this should make absolutely clear how external loads are transferred to the supports of your structure) – you could also indicate different types of structural elements of your structure and their role/ contribution to the overall load path.*
- *Draw a free body diagram of your design – this can be also used as supporting argument for the overall stability of your structure.*
- *Consider the strength to weight ratio of different structural materials and provide arguments for the choice of the material(s) of your structure with respect to the ultimate limit state.*
- *Consider the modulus of elasticity of different structural materials and provide arguments for the choice of the material(s) of your structure with respect to the serviceability limit state.*
- *Provide a simple calculation (no more than 3 lines) for your structure that shows that the ultimate limit state is satisfied.*
- *Provide a simple calculation (no more than 3 lines) for your structure that shows that the serviceability limit state is satisfied.*

The assessment for this module focuses on four key criteria: Innovation, Process, Sustainability and Communication.

Final presentation
The project concludes with a final presentation in Week 29 where the students exhibit their development work (sketches, models, analysis and prototypes), along with their final engineering drawings (demonstrating context and relevant detail), in the design studio and install and present their final prototypes on site (Figure 2). Intentionally, this is an event that requires a range of communication skills to a large and diverse invited audience.

The awareness of the significance of this event helps drive the momentum of design development throughout the module and provides a significant opportunity for the students to take pride in their projects, appreciate what other groups have achieved and reflect upon the project as a whole.

The audience includes staff from across the Faculty (academic and technical), structural engineers and architects from external companies, and students from all year groups of the Civil Engineering programmes.

Awards
Two group awards, the First-Year Civil Engineering Design Award and the First-Year Civil Engineering Drawing Award are awarded each year.

Project evolution
An increase in the number of students taking the course from 46 to 78 and the realisation of new design studios, associated technical support, and a broader range of hand tools and materials has led to designs of greater scale, ambition and craft.

Other changes have included:

- an increased focus on the skills and processes required for effective team

working and the opportunity for individual students to provide anonymous peer feedback regarding their teammates and to reflect upon their own contribution to the design
- an increased focus on drawing, diagramming and visualising analysis by hand (students are provided with A5 note/sketch books, pens and a propelling pencil)
- clearer and earlier signposting of expectations using project examples from previous years, design precedents from varied sources and increased discussion regarding what makes design effective
- an increased emphasis for students to tackle structural types, forms and geometries that they are unlikely to be able to fully calculate.

These changes had a positive impact on the productivity, ambition and structural sophistication of the student output and in-progress project outputs from the 2017/18 academic year. Projects in development include timber shells, a beam made from pre-tensioned recycled drinks cans, double curvature arches and a 6m tall tapering gridshell.

Example projects from 2015/16 to date

The traversing arch structure shown in Figure 3, comprising 11 box sections, spans between two masonry walls that act as abutments to withstand the lateral forces imposed by the arch form. Chords run through the centre of the box sections allowing for ease of installation and to counteract shear forces at the connections. The box design is effective in withstanding the compressive forces within the arch.

Figure 4 Project example from 2016/17

Figure 5 Project example from 2016/17

"THE TRIANGULAR CROSS-SECTION OF THE TRUSS IS INHERENTLY STRONG"

The traversing structure shown in Figure 4 spans between a ramp and a flight of steps. The structure is located perpendicular to the descending ramp; its cross-section tapers to provide the greatest structural depth at its centre, and is widest at its ends to resist torsional forces generated by the sloping support.

The traversing structure shown in Figure 5 spans between the top of a low-level wall and the adjacent stepped ground level. The triangular cross-section of the truss is inherently strong, provides lateral stability and resists torsional forces. The top cord of the truss has been designed to align horizontally with the top of the wall, thus emphasising the change in site levels and resulting in a structure that tapers over its length. Steel weights placed within the structure at each end are sized to

Figure 6 Project example from 2016/17

Figure 3 Project example from 2016/17

counteract the calculated horizontal forces and overturning effects applied by wind loading. The structure is constructed from laminated, and offset, sections of laser-cut plywood, which results in an extremely high strength-to-weight ratio.

The 'lookout' structure shown in Figure 6 leans against the corner of an adjacent building and uses its geometry to direct the viewer's eye towards a distant landmark. The prismatic form is wider at the base to provide stability and narrows and deepens at its midpoint to reduce weight and achieve structural strength. The interconnecting

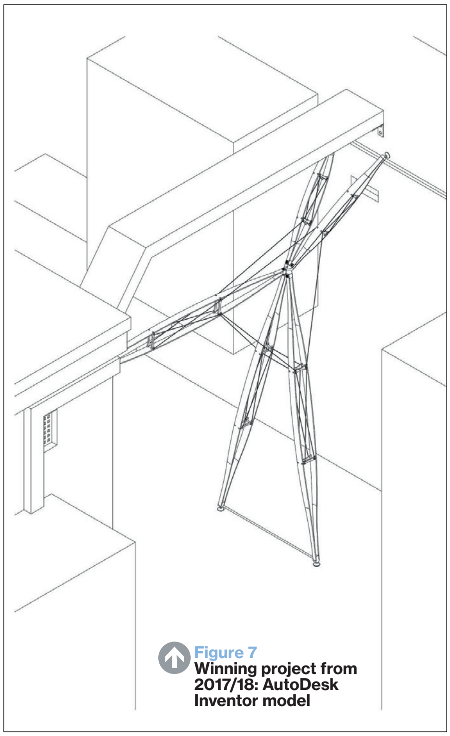


Figure 7
Winning project from 2017/18: AutoDesk Inventor model

Figure 9
Project example from 2015/16

Figure 10
Example final prototypes, connection details and development models (2015–17)

structural cords provide stiffness, help visually realise a lightweight structure, and are connected by a series of 3D printed nodes.

Figure 7 illustrates a traversing structure designed to cantilever across a walkway linking two buildings. A central 3D printed node connects five elements. Four leg elements resist vertical/horizontal load and level/align the structure to ensure stability. The final element cantilevers across the walkway, stopping just short of the wall. Each element utilises the bending forces in the timber members and ties, which reduces weight and provides an efficient structural form.

The traversing structure shown in Figure 8 sits on top of a parapet wall and is formed by two cantilevered and tapered cardboard beams. The beams are connected at their ends to create a symmetrical structure that elegantly rises and falls to clear a mid-span obstruction, a structure that is balanced and that uses material economically. The outer, folded layer of the structure is strengthened by box sections and ribs on its underside, riveted connections are reinforced with plywood washers and bolted connections allow for assembly/disassembly and the levelling of the structure on site.

"THE OUTER, FOLDED LAYER OF THE STRUCTURE IS STRENGTHENED BY BOX SECTIONS AND RIBS ON ITS UNDERSIDE"

Figure 8
Project example from 2015/16

The traversing structure shown in Figure 9 has been designed to span across a courtyard between a retaining wall and an opposing windowsill. The structure consists of two separate steel-framed sections, allowing for transportation and storage logistics, minimising mechanical joints, reducing distortion during welding and facilitating the structure's cranked form, which allows for pedestrian access underneath. The frames' tapered sections are deepest at midspan where they meet and the bending action is greatest, but reduce in depth towards the supports, minimising the weight. This realises elegant proportions and results in a structural form that sits delicately within its context.

Figure 10 shows final prototypes, connection details and development models from 2015 to 2017.

Impact on student design achievements in Parts 2, 3 and 4

The opportunity to enthuse and raise the ambitions of our students in their first year has had a significant impact on their approach to challenging design briefs set within Parts 2, 3 and 4. This has resulted in projects demonstrating greater bravery, thoroughness, structural resolution and verve. These outputs are actively promoted throughout the Civil Engineering courses to encourage ambition and to illustrate achievable goals. A healthy supportive and competitive spirit has been generated among the cohorts. Example outputs are shown in Figure 11.

Faculty Design Show

Engineering and the Environment held its first Faculty Design Show in 2015 with the aim of adding momentum and ambition to the design curriculum. Held each year in Week 37, this provides a further opportunity for first-year Civil Engineering students to present their structural prototypes. A catalogue of first-year projects can be found on the Design Show website (www.uosdesign.org).

Value in teaching structural engineering design holistically

It is important that our students are taught to consider structural engineering design holistically, to understand its broader contexts and the positive cultural and societal influence that it can have. Our students are highly capable and limiting their structural engineering education (engineering education generally) to pure theory would be a disservice and fundamentally lack the challenge through application that results in effective engineering design rather than the theoretical limitations of engineering science. Such an approach serves to strengthen fundamental knowledge and allows our students to consider their future position and influence within engineering – it is exciting and limitless.

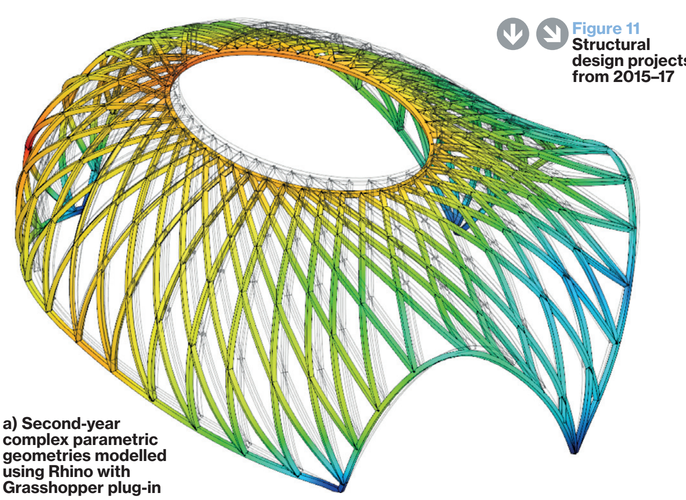
Structural engineering role models such as Frei Otto, Jürg Conzett, Ove Arup (Total Design), all of whom have realised designs that challenged convention and that are of their time (material use, construction processes, cultural influences), are often used. Along with role models from architecture (Richard Rogers, Norman Foster, Peter Zumthor), product design (IDEO [human-centred design], Apple), as well as tailored influences to suit individual student ideas and proposals.

We are looking for a Southampton graduate to have a fundamental knowledge of engineering science and the need to be rigorous in its application, but also to understand that solving an engineering design problem requires them to take 'risks', embrace the unknown and be brave.

Conclusions

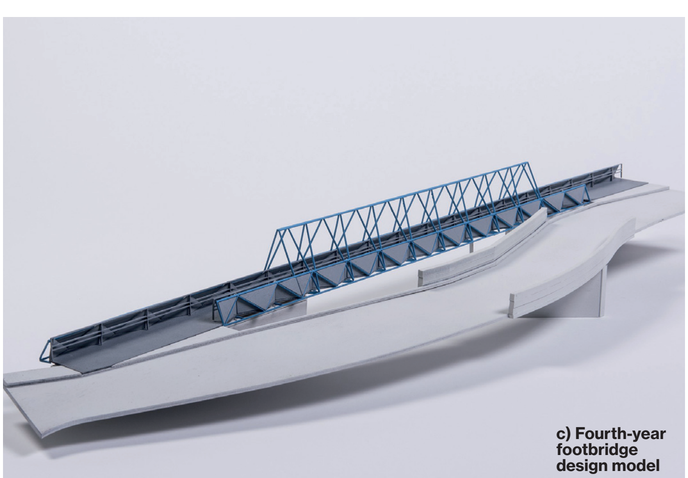
Prototype provides a challenging activity that encourages experimentation, the development of unique structural design proposals (owned by the students) and the

Figure 11 Structural design projects from 2015–17



a) Second-year complex parametric geometries modelled using Rhino with Grasshopper plug-in

b) Full-scale construction of student design



c) Fourth-year footbridge design model

d) Revit model of building interior

"IT IS GREAT TO MEET STUDENTS SHOWCASING THEIR HIGH-QUALITY PROTOTYPES, THE FINAL PRODUCT OF THEIR DESIGN PROJECT. THEY RIGHTLY TAKE PRIDE IN THEIR WORK WHILE PRESENTING IT WITH A MIXED AUDIENCE, INCLUDING PRACTISING ENGINEERS. I PARTICULARLY ENJOY DISCUSSING WITH THEM THEIR DESIGN JOURNEY, WHICH IS ALWAYS WELL SUPPORTED BY A VARIED RANGE OF VISUAL AIDS. IN DOING SO, I WONDER HOW MANY OF THEM IN THEIR FUTURE PROFESSIONAL CAREERS WILL TAKE THE SAME PRIDE IN THE FINISHED PRODUCT OF THEIR DESIGN WORK AND I HOPE THAT MANY WILL DO."

FABIO GAZZOLA, PRINCIPAL ENGINEER: CIVIL STRUCTURES, RAMBOLL

production of high-quality design outputs to act as a vehicle for students to holistically develop core engineering skills and abilities (rather than dividing into separate standalone elements).

The activity embeds the production of prototypes into the design process to provide sequential testing milestones and to encourage continued project development – there is always an opportunity to develop the project further and produce another design iteration and prototype. This removes any perceived cap to the activity and allows the most ambitious students to excel, as well as the year group as a whole to benefit.

The importance placed on communication skills and visualised outputs within the design process is integral to unlocking the student's potential to experiment and for that experimentation to mix the development of their theoretical knowledge with a developing awareness of their own personal approach to design.

Specific achievements of innovative activity and associated learning outcomes are highlighted below. Prototype:

- provides an 'in practice' introduction to design as an iterative process
- encourages and motivates students to be creative, self-teach, apply judgement, make decisions and act independently
- requires regular communication throughout a design process with team members, staff tutors and requires students to formally present their final proposal to an audience involving industry representatives and more broadly within the annual Design Show (adding value through celebrating unique achievements).
- involves the use of fundamental structural behaviour and analysis to refine and resolve a structural design as an integral element of a holistic design proposal
- integrates a detailed site survey process to introduce rigorous observation and analysis and to apply this to the development of site-specific design proposals
- encourages students to look at and analyse a diverse range of design precedents and apply their understandings and observations to aid the resolution of their design
- introduces:
  – hand sketching and technical drawing based on industry standards (plan, section, elevation, isonometric, scales, dimensioning, line types, annotation, layout sheets)
  – computational modelling focused on AutoDesk AutoCAD and AutoDesk Inventor – with an opportunity for students to use alternative software, i.e. Rhino + Grasshopper.

There is often the thought that students can't (or shouldn't be asked to) tackle a design problem until we have delivered specific theoretical content that sets out how to solve the problem – within structural engineering education this generally means until they can fully calculate the solution. We have demonstrated that this is ultimately a limiting approach and have developed an activity which overcomes this.

Acknowledgments

The realisation, evolution and success of this project and broader design curriculum developments have been made possible by a range of people within the faculty. The strategic investments in education (Professor Anna Barney) and faculty infrastructure (Professor David Richards) by the Faculty Leadership Team, Programme Directors/ Leads and staff within Civil Engineering (particularly Dr Alan Bloodworth, Dr Mehdi Kashani and Professor Theodore Karavasilis) and the support of the faculty's technicians. The integrated support from visiting architects and structural engineers has also been fundamental to the success of the project (Mr Carl Leroy-Smith and representatives from Ramboll and Arup).

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