Kenneth Severn Award 2017

How should structural engineers balance safety and serviceability requirements with a human desire for elegance and beauty?

Our health and well-being is affected by our environment. The appearance and character of the built environment around us strongly affects how we feel, and structural designers should be concerned with creating elegance and beauty as well as ensuring safety and serviceability.

Describe the contribution of structural engineers towards creating an elegant, attractive and appropriately human-centred built environment, and suggest what changes in their education and professional development might enable them to do this more effectively.

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Synopsis

The Institution of Structural Engineers' Kenneth Severn Award is an annual essay competition for young engineers in which the question is set by the President. In this essay, 2017 winner Amy Cleaves considers how engineers can be educated to achieve elegance in their designs.

What is elegance?

Beauty is a combination of qualities that pleases the intellect. Elegance requires much more. Design cannot only be beautiful, but needs to satisfy more requirements, to be the simple solution to complex problems. To attain an elegant solution, engineers need to be mindful of the following three elements[1,2]:

- the needs and context for which we are designing (the structure should be durable and appropriate in both material and style, efficient in function, and maintenance costs should have been considered)
- the natural properties of materials and the relevant fabrication processes to meet the forces and conditions encountered on site (the structure should be capable of being constructed with ease, safety and speed, and be environmentally sympathetic)
- the nature of current society and the economic climate (to provide a socially sympathetic and economically efficient structure).

The 1989–90 Institution President, Dr J.H. Armstrong, observed that 'social and economic pressures and policies, fashions almost, change continuously in any free society. The task of the professional is to adapt to these changes without sacrificing the essential qualities of his service'[1]. An elegant solution is durable to changes in style, beauty, and social and economic climates, while fulfilling the essential safety and serviceability requirements.

Three ways to achieve elegant design solutions have been identified:

- through **iterative design**
- through **innovation**
- through **synergy**.

Elegance through iterative design

Engineers design to fulfil the three elements outlined earlier, but may not always arrive at an elegant solution. In our industry, there is not only one solution. Design should be iterative by 'minimising and minimising again until only utility and beauty are left'[3].

Elegant buildings look effortless[3]; the details appear to be fortunate coincidences rather than a well-considered design; however, this is rarely the case.

The roof of the Sydney Opera House called for a repetitive geometry so that the ribbed shells could be prefabricated to reduce cost and construction time and so that the exterior could be uniformly tiled, but each shell was required to look architecturally different. It took years for Ove Arup and the architect, Jørn Utzon, to arrive at a mathematical design, eventually using a sphere to achieve the shapes[4] (Figure 1). Many other forms for the curve were considered before arriving at this optimum solution, including parabolic and elliptical functions; however, both would have added expense as formwork and prefabrication would be hindered due to the differing angles along a varying curve.

Elegance through innovation

Engineers have a responsibility to the architect to deliver their vision, including a professional responsibility to maintain the utility and robustness of the structure and ensure safety standards are met[1]. There should never be a compromise on safety; however, a goal to achieve function only does not push us as engineers. An architect who asks an engineer for a simpler, more beautiful design has the ability to drive an innovative design. Further constraints, be it social, economic or environmental, should be viewed as a challenge from which we innovate. Multiple designs can achieve the same function and safety standards, but they should be refined to elegance.

James O'Callaghan is innovative in his approach to glass engineering, delivering the client's vision while also providing safe and usable structures[5]. These elegant designs have only been achieved through developing past designs and technologies. This innovation can be clearly seen in the contrast between O'Callaghan's 2011 redesign of his own structure, the Fifth Avenue Apple Store in New York, and the original built in 2006[6] (Figure 2).

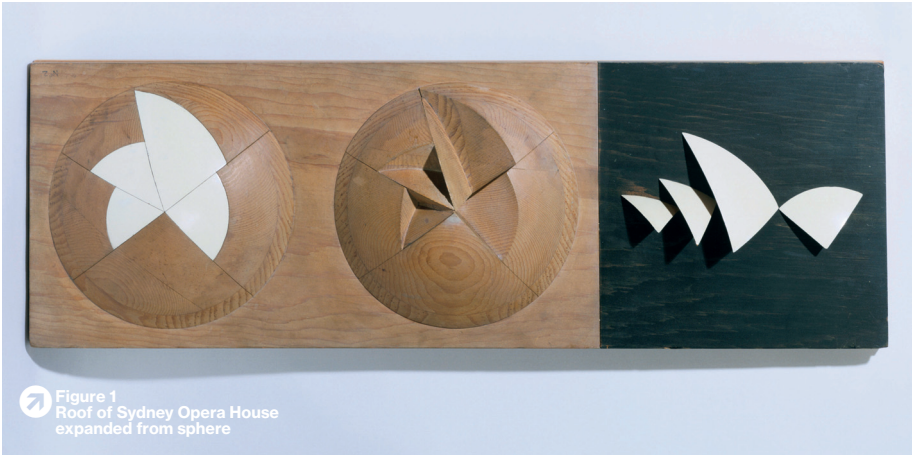

Figure 1
Roof of Sydney Opera House expanded from sphere

RIBA

> "ELEGANT BUILDINGS LOOK EFFORTLESS; THE DETAILS APPEAR TO BE FORTUNATE COINCIDENCES RATHER THAN A WELL-CONSIDERED DESIGN"

Beauty should not be sacrificed for serviceability; they should come together. Structures can be read when elegant and simple. Simplicity aids safety and design of deconstruction or renovations to the structure, as the load paths and stability systems are apparent.

Elegance through synergy

Elegant structures can only be achieved if all designs work together; structural design at its best incorporates the interaction of a structure with services, finishes and its environmental setting, not only the structure itself[2]. Synergy within the design team to achieve one collaborative design is key to create an elegant building.

Education

Elegance and beauty are an emphasis on design, whereas serviceability and safety are an emphasis on structural analysis and site management[2]. The education of aspiring engineers should balance the two.

The majority of the university syllabus concentrates on structural analysis; a young engineer cannot design a concept scheme without the knowledge and experience required to ensure the scheme will work. 'Universities cannot provide fully trained designers: it takes 5–8 years in practice to become fully competent.'[7]

However, it is argued that a university syllabus is academically rigorous and guides students towards an academic future rather than an engineering career. 'Design is the basis of engineering making its teaching an important ... issue.'[2]

Instead of aiming to teach students to be fully fledged designers within the time constraints of a Master's degree, universities should teach the three tools to achieve elegant design solutions:

- iterative design through design experience
- innovation through experimentation
- synergy through teamwork skills.

To achieve an elegant design requires experience[3], so this needs to be passed on efficiently to students. Two areas have been identified within undergraduate degree programmes where experience from practising engineers could be passed on more efficiently:

- **design teaching**
- **industrial placements.**

Improving design teaching

Design teaching can be improved through:

- team projects
- problem-based learning
- employing visiting professors.

Team projects

Design is seen as a stimulating part of an engineer's work and, when incorporated into the curriculum, there is a positive reaction among students[2]. The University of Bath combines design projects between architects and engineers, to create a design team. This cooperative environment encourages good teamwork, which should be practised at university; 'more interdisciplinary projects are necessary so that students are also exposed to the viewpoints of architects, sociologists, and artists'[2] and learn how to incorporate them into their projects.

Problem-based learning

Some medical schools use problem-based learning (PBL) to incorporate different areas of study into solving one, open-ended problem[8]. The students gain soft skills in teamwork, presentation skills and independent learning, as well as gaining knowledge in a vocational setting with a holistic approach. A PBL teaching style could be applied to design teaching in engineering education. 'Undertaking design projects, particularly in multi-disciplinary teams, is the best way to develop engineering design ability in students ... One of the best approaches, though resource heavy, was to use design, build and test projects which increased motivation and brought home the lessons about design more effectively than paper-based projects.'[7] Design-and-build projects encourage students to experiment, to learn to cope with project restraints and materials, and to sympathise with the environmental context of the project.

Visiting professors

Good design teaching requires good design experience, which can be considered lacking in academic staff, due to academic research being their main priority[2]. However, some universities already employ visiting professors, who are practising engineers. This should be encouraged by:

- providing more funding to pay design teaching staff, as universities 'do not have funds with which to reward such input

KENNETH SEVERN AWARD 2017

Winner:
Amy Cleaves, Integral Engineering Design

Commendations:
Alastair Low-Macrae, AKT II
Matthew Powell, Sweco
Krishna Prasad Menon, Atkins

2006 design: 106 panels

ALAMY

Figure 2
Iterations of Apple Store, Fifth Avenue, New York

2011 design: 15 panels

ALAMY

and the commercial organisations cannot afford to give their employees free time to go teaching'[9]

- making more jobs available for engineers to practice part time and teach part time[2]. This will need to be made desirable for an engineer in the workplace, e.g. awards for teaching excellence will 'emphasise the importance the institution gives to the education of its future members'[10].

Improving industrial placements

Veterinary science degrees ask for compulsory extra-mural studies (EMS) whereby the student must complete a certain number of hours of clinical placements within each academic year before they are allowed to progress[11]. This idea could potentially be transferred to engineering programmes to inform students about the industry[9], their professional responsibilities, and the nature of iterative design processes.

Holiday time would be used productively and this would not prolong degrees in the way that a sandwich course, which includes a year in industry, does. However, some students rely on earning an income during their holidays, which not all EMS placements would be able to provide, giving an unfair advantage to students with more prosperous backgrounds.

EMS placements could improve syllabus choices at university and links between industry and academia; employers will take an interest in what is taught , particularly if students return to a graduate position.

Conclusion

Elegant structures can be achieved through an iterative design process, innovation and experimentation, and collaboration within the design team, without compromising safety and serviceability. In education, PBL, industry experience through placements and teaching, and teamwork are critical to becoming a competent structural designer.

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