# Use of Physical and Numerical Models in Engineering Design Education

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## Abstract

The use of physical models in understanding design concepts and processes is an old tool that early engineers recognised the importance and adopted at the very earlier stages in their design concept. For example, traditionally, bridges, tall building, aircrafts and cars, have always been small-scale modelled and investigated for wind loading. The advent of computers and sophisticated IT tools has meant that increasingly more emphasis is being put of numerical modelling, sometimes at the expense of physical modelling. The present paper describes and discusses the importance and impact of using physical models by engineers as a powerful aid tool to a better understanding structural engineering design, and appreciation of the implication of their choice from the conceptual to the final realisation stage. The paper reviews the experience of undergraduate students at Coventry University by providing typical examples and highlighting the benefits of such experience.

## Keywords
Physical models; engineers; IT; architects; design; benefits.

## 1. Introduction

In the United Kingdom, as well as in the other countries, the approach to conceptual design and the design process exhibited by engineers is essentially engendered and shaped during their university education. In some institutions, engineers study and interact with architects, but in may others this is not possible, and engineers are often not exposed to a holistic approach to design that encompasses all aspects of design but also the impact of decisions made on other aspects of life such us society and the environment.

With the advent of more and more sophisticated computer software, more emphasis is being put on IT as a means of conducting and fulfilling the design process. Although there is no doubt, IT is very important in the design process using this approach can only widen the gap between the way engineers think about their structures and the way they appreciate the implications of their choice of form, from the conceptual to the final realisation stage, and beyond. Not enough time is therefore spent developing a feel for structural response or behaviour. Engineers are sometimes pushed by educational institutions towards the more systematic approach to design via a progression in example design difficulty without lateral thinking. The start must be at Universities and educational establishments. As Tietz (1997) stated: "undergraduate education needs to place more emphasis on studio-based teaching, with experienced designers brought in from practices to assist on a part-time basis. More interdisciplinary projects are necessary, so that students are also exposed to the viewpoints of architects, sociologists and artists".

Figure 1 shows an example of a physical model of a suspended railway bridge, whereas Figure 2 shows a physical model of the Akashi Kaikyo Bridge (Japan) in a Wind Tunnel where it was subjected to experimental testing to varying wind speeds and loading. Figure 3 shows the actual bridge in operation. Numerous papers were published describing the physical modeling and experimental results from testing of the model (e.g. Miyata and Yamaguchi, 1993).

There is no doubt that information obtained from models and testing of models is crucial and of great importance into developing an understanding of the behaviour of the actual structures and methods of efficiently designing it through lessons derived from the physical and/or numerical modeling and analysis. The main thing to always bear in mind is that the physical/numerical model is good as long as it is an accurate representation of the actual structure. This may be achieved through carefully modeling the structure as far as its geometry, material(s), restraints, loading and environmental parameters affecting its behaviour are concerned.

For students, the above are not so important, since the prime aim is develop awareness in them as to the different shapes and forms of structures, the use of different materials, the importance of adequate restraints, and potential construction problems, feasibility and estimated cost.

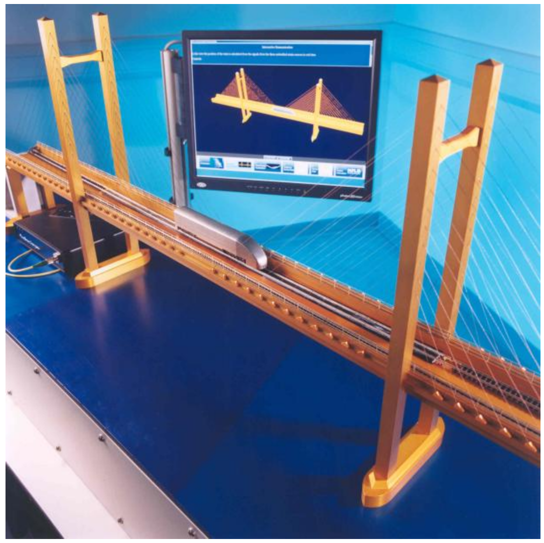

Figure 1. Physical and computer model of a railway bridge (Courtesy of NPL: http://www.npl.co.uk/materials/functional/fos/bridge.html with permission)

(a) Bridge model in wind tunnel (b) Actual bridge

Figure 1. The Akashi Kaikyo Bridge
(Courtesy of Department of Civil Engineering, National Taiwan University)

## 2. Design at the Heart of Engineering Education

In engineering a central activity is design, and the interpretation and execution of design. This may be as an individual or as part of a team. The engineer involved in the design process will be required to exercise continuous judgement, adaptation, modification, ingenuity and nearly always imagination and flare. It is vital, therefore, that engineers receive in their early education a thorough grounding in those activities that are central to the design process (Engineering Council, 1998).

Any good design will have certain typical features: simplicity, unity and necessity. Factors in design are function, safety and economy. Additionally, the process of design includes an appreciation of the project requirements; formulation of schemes; appraisal of schemes; analysis of final scheme; details and specifications; supervision of construction (The Institution of Structural Engineers, 1969).

When any loads require to be supported, it is the aim of the structural designer to propose a system of members that can provide a safe and economical structure to fulfil this purpose. To do this requires an understanding of how any proposed arrangement of structural members will deform and behave (Brohn, 1991). Stages in structural design include conceptual design and planning. This involves selecting the most economic structural form and materials to be used. Preliminary designs are often necessary to enable comparisons to be made. Idealization of the structure is then required for structural analysis. The structural designer uses knowledge of structural mechanics and design, materials, geotechnics, design codes and standards, and combines this with practical experience to produce a satisfactory design. In order to make decision and to carry out complex analysis and design calculations, advice from specialists may be required, as well as use of codes, design aids, handbooks and computer software to help in this process. Students very often lack the necessary experience and as such find making decisions about form very difficult (MacGinley, 1998).

Elementary structural analysis is concerned with skeletal structures or structures that can be represented by lines and properties associated with lines. In order to learn to model structures properly, it is important to observe structures and try to understand how they function (Spillers, 1985).

The use of physical models can help to improve understanding of how structures are put together and how they work. These models can also be put to good effect in helping engineers and architects communicate their ideas.

## 3. Design in the Department of Built Environment

Students in the Department of Built Environment at Coventry University are introduced to design at the early stages including induction week. A design and build project is carried out in that week which also acts as an 'ice breaker' for new students. A 'Technical Drawing and IT' module at level 1 formally introduces new students to the concepts of design through drawing and CAD work.

At level 2 all students study the 'Structural Design' module which focuses on structural design in reinforced concrete, structural steelwork, timber and masonry. Broad design concepts and principles are established and students are made aware of the requirements of the appropriate British Standards.

At level 3, depending on the chosen specialism, students can study the module in 'Civil Engineering Design'. In this module students in teams pursue conceptual and detailed design solutions to a range of Civil Engineering problems, often drawn from 'real life' situations. In recent years examples have been the design of a proposed new university, a hotel complex, and an office block development. At this level design projects are more open-ended and allow students to apply their knowledge across a spectrum of subjects in order to solve technically challenging design exercises. Students are required to present the outcome of their design studies in a variety of ways including technical reports, drawings and presentations. A double 'Project' module is also undertaken.

The teaching of safety issues in design is part of Design teaching within the Department where the requirements and implications of Codes of Practice are introduced and developed as an integral part of design philosophy (Coventry University, 1999). This is also a requirement of accrediting bodies such the Joint Board of Moderators (JBM).

## 4. Introducing New Students to Design

Design for the first year one undergraduate students starts with the induction week 'bridge building competition'. Students are required to construct a bridge structure of minimum weight of materials to span 600 mm and to carry as a minimum a specified weight.

The specification for the materials provided are that structural members can be made of Balsa wood and string. Joints can be made using glue, pins, or string. Thin card is provided which can be used for the deck and as a structural stiffener. The most effective bridge was judged to be the one that carries the highest load to collapse using the least material weight. The bridge structures were weighed before being load tested in a rig. The load was applied at the centre of the deck span via the rig plunger mechanism.

Before starting, the students are asked to typically consider the types and nature of bridges previously seen for example over motorways, rivers, railway lines, and so on. For their selected type after sketching several possible solutions they are asked to consider how easy is it going to be for their structural members to be connected together? Which of their members are being compressed and which are being pulled apart when loaded? What effect does member slenderness have on member behaviour when loaded? How is bending, shearing and bearing of the structural elements allowed for? How will overall stability of the structure be achieved? How will excessive deflection be controlled? How does the overall depth affect the strength and stiffness of the structure?

At level 1, at the end of the second term, students are given a design project. The objective of this project is for students to apply the skills acquired in other relevant modules such as structural mechanics. For those students who carried out the bridge building exercise during induction week this is a chance to undertake a similar exercise using all of the new skills they now have.

Each student group is required to construct a bridge which is to have lightest weight while meeting a similar specification to that originally given. The essential difference however is that now a minimum load to be carried of 15kg point load at centre span is specified, and a maximum deflection of 2mm at centre span with 10kg load.

Students work in groups of three to six people. This is in order to develop a team-working approach to problem solving. Laboratory work requires groups to obtain samples of the materials and arrange to test them to determine their properties. Design work involves the use of computer packages in order to carry out any necessary analysis or alternatively, manual calculations are acceptable if more appropriate. Figures 1 and 2 show some typical examples of bridge models constructed by first year students.

Figure 1: Typical bridge models

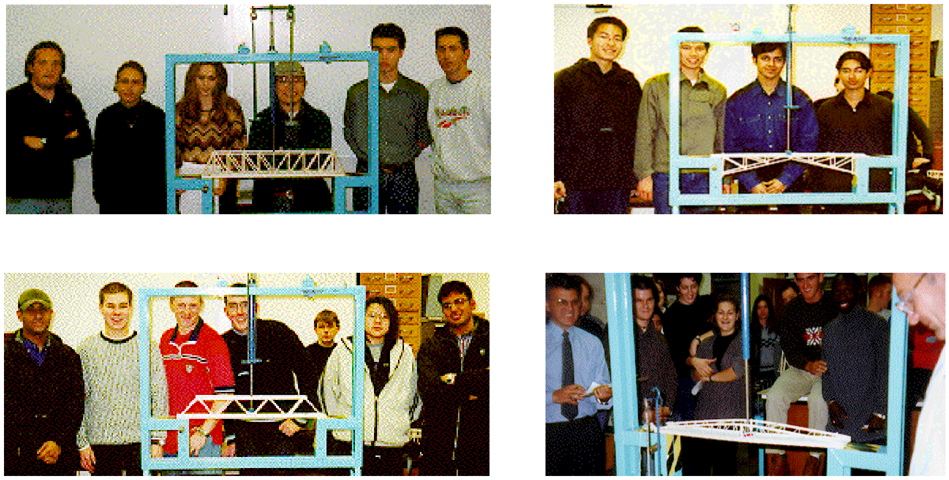

Figure 2: Typical bridge models in the test rig

## 5. Final Year Design Projects

Coventry University does not have a Department of architecture as such, and therefore can not exploit the possible interaction between future architects and engineers. There was an awareness that something had to be done in order to face this challenge in order to bridge the communication gap between engineers and architects. Final year design projects are used as a vehicle to achieve this goal. This is done through the use of physical modelling and studio-based projects. The result is the development of a sense of awareness in engineers that design is not a mere use of a computer and few lines of calculations or using design standards. Indeed, as part of their project, students are strongly encouraged and guided to undertake an integrated approach to design. This involves the exploration of different options, implication and integration of the design with its surrounding environment and social context. All are carefully considered at the different stages of the design process as shown in the flowchart in Figure 3, as well as physical modelling of the structure.

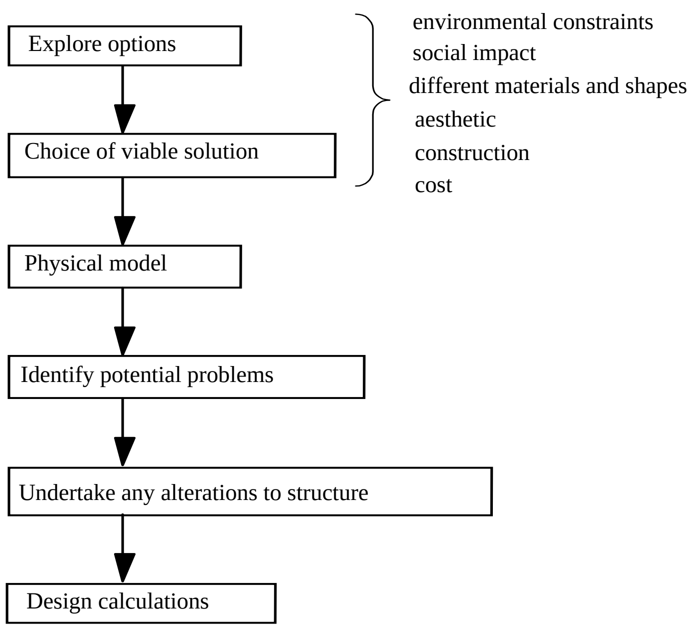


Figure 3: Flowchart of an integrated design process

Students are encouraged to think laterally, explore on their own, and also visit engineering practitioners and architects to learn how to exchange and take on board the views of others. Figures 4 and 5 show examples of the models built by students as part of their design projects, some them winning national recognition (Lo, 1997), and (Fergusson, 1999). Design projects have become very popular at Coventry; they have passed from being a boring subject to an enjoyable experience where the individual's imagination is stretched to the limit. All students who were asked after completing their project about their experience said that they had enormously enjoyed it and were considering of choosing a design career. The experience has also given an insight of both the work of architects and engineers and how the two complement one another in producing elegant, robust and cost effective structures.

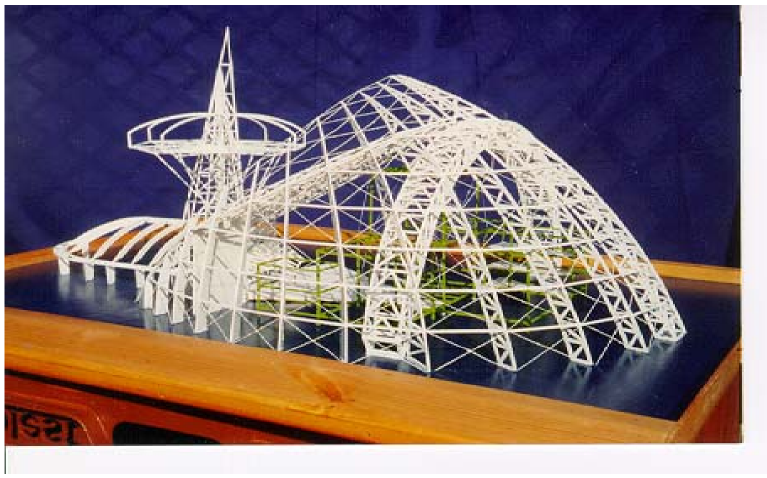

Figure 4: Example of a model of a theatre and restaurant

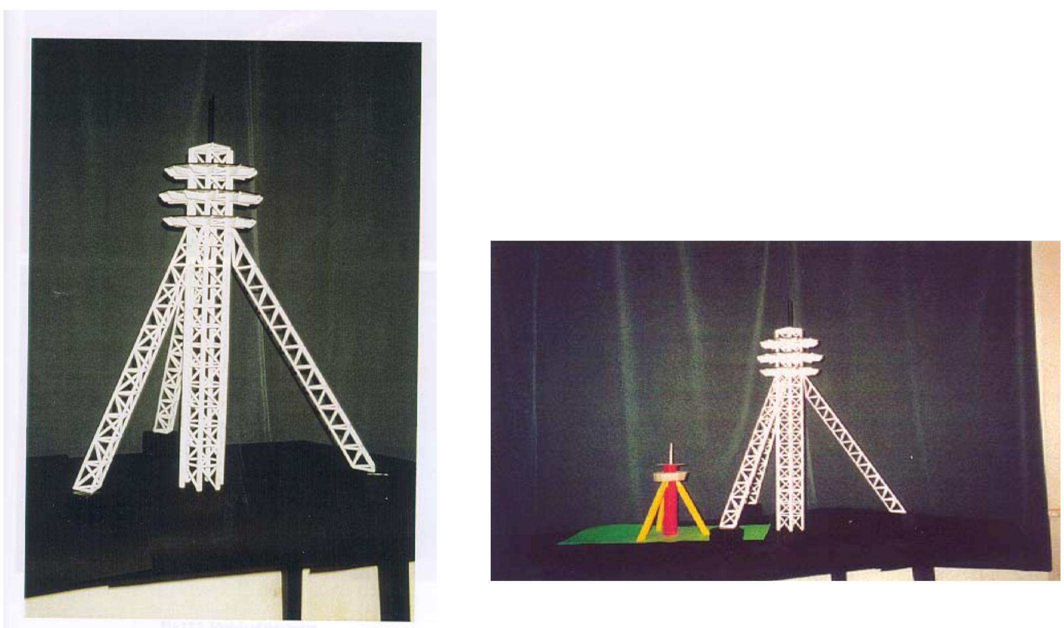

Figure 5: Example of a model of a telecommunication tower

## 6. Benefits of Physical Models or Studio-Based Learning

The benefits of physical modelling and studio-based learning to engineers may be summarised by the 6 following points:

(i) It develops the engineer's sense of imagination

(ii) It helps the engineer understand the structure that is being designed
(iii) It helps identifying potential problems (e.g. stability, construction problems)
(iv) It helps the engineer make modifications and improvements with relative ease
(v) It gives the engineer possibility to view structure from different angles
(vi) It help with eventual computer modelling of final structure

## 7. Conclusions

The use of physical models and studio-based learning in educating and teaching engineers is a very useful tool. The earlier students are exposed to design, particularly in groups, the more beneficial the experience. This is because it opens the gates for students to explore and exploit their creativity, imagination, and inner abilities. Physical modelling enables students to augment their understanding of their structure. It enables them to consider and address such things as structural complexity; load transfer; stability and element connections as well as other areas. Studio-based learning means making decisions, being innovative, and using judgement. It is an important part in the design process and should be included in university curriculum, especially when it helps bridging the communication gap between architects and engineers. It is the first step towards a relationship of mutual understanding and co-operation that can only be of great benefit to the construction profession as a whole.

## References


[1] Tietz, S.B. 1997. Design education. The Structural Engineer, Vol.75, No.18, pp.325-326.
[2] Engineering Council SARTOR 3 Accreditation Document. 1998. Annex B.
[3] Aims of structural design. 1969. The Institution of Structural Engineers. 11.
[4] Brohn, D. 1991. Understanding structural analysis. 2nd. Ed. BSP Professional books.
[5] MacGinley, T. J. 1998. Steel Structures Practical Design Studies. E & FN Spons.
[6] Spillers, W. R. 1985. Introduction to structures. Ellis Horwood Ltd.
[7] Coventry University, School of the Built Environment. 1999. JBM&JAP Accreditation Document.
[8] Lo, K.Y. 1997. Conceptual theatre design and analysis. Final year B.Eng. project. School of the Built Environment, Coventry University.
[9] Fergusson, M.J. 1999. Conceptual theatre design and analysis. Final year B.Eng. project. School of the Built Environment, Coventry University.
[10] Miyata, T; Yamaguchi, K. 1993. Aerodynamics of wind effects on the Akashi Kaikyo Bridge. Journal of Wind Engineering and Industrial Aerodynamics. Vol. 48, no. 2-3, pp. 287-315.


## Biography

**Messaoud Saidani** completed his first degree in Civil Engineering at the University of Science and Technology in Algeria, where he won the Best Student Award. He then completed a PhD in Civil Engineering at Nottingham University under the supervision of Dr Martin Coutie (author of the famous 'structural analysis' book co-authored with Coates and Kong). Messaoud then stayed on as a post-doctoral research fellow for four years working with Prof David Nethercot on a number of pan-European and UK projects (total value in excess of £4m). Messaoud then joined Coventry University in 1995 as a lecturer, then senior lecturer, and finally as a Reader in Civil Engineering, and for nine years also taught at the University of Warwick as a visiting lecturer teaching structural analysis and design. For the past five years he has been a visiting Professor at the University of Science and Technology in Algeria. He recently became a Chartered Engineer and a Member of the Institution of Structural Engineers. He is also a member of the International Society for Structural and Multi-disciplinary Optimisation. Messaoud is currently Associate Head of Department (Civil Engineering), in charge of managing its undergraduate and postgraduate programmes and its applied research portfolio including the preparations for the REF2014. Messaoud published over 70 journal and conference papers, and technical documents.