

## **DEFLECT: A Computer Aided Learning Package For Teaching Structural Design**

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### *Abstract*

*The teaching of structures and its integration with design teaching has been seen as one of the major problems in design education in schools of architecture world-wide. A number of suggestions have been put forward to improve the quality of teaching in structures in architecture. These include the production of computer based learning materials, and the use of the computer as a 'substitute' tutor.*

*This paper reports on a SHEFC funded project jointly carried out by the Department of Civil Engineering, University of Paisley, the Mackintosh School of Architecture, and Lamp Software. The project aims to build a computer-assisted learning package on the response of structures to load. The software will be used as an interactive teaching tool for both architectural and engineering students.*

*The package has three levels: Beginners (Level 1), Intermediate (Level 2) and Advanced (Level 3). The first two levels have been completed after continuous feedback from both institutions. Level 1 is geared towards architectural and engineering students to help them understand structural behaviour of building components, such as deflection. Level 2 is a graphical editor that enables students to draw precisely the structure of their designs, investigate the deflection of structural members and identify areas of tension and compression. Level 3 is a design tool aimed at architectural and civil engineering students where they can design and analyse realistic structures by choosing structural members from a library, and specify materials and multiple loads.*

*Prior to its final release, the software package was appraised by students from both institutions. Analysis of results from questionnaires revealed that students expressed a great deal of 'satisfaction' with many of its teaching and learning attributes. The outcome of this project will promote and enhance students' understanding of the response of structures to load; it will also help students grasp the impact of varying building materials and cross sectional properties on the structural form.*

### **Introduction: Structures in the Architectural Curriculum**

In the course of more experience of architectural teaching and examining than one cares to admit, it has been both interesting and rather depressing to note how many architecture students, even in their final year, have clearly not understood basic structural concepts, or how structures work. There appears, in particular, to be widespread difficulty in grasping whether something is in tension or compression, and the suggestion that diagonals in a truss may need to change direction in mid-span can be met with astonishment, aesthetic objections, embarrassment, or even tears. Given the desirability of a productive fusion of structure and concept, the major importance of structure as one of the factors the designer can exploit, this seems strange, but it is demonstrably the case.

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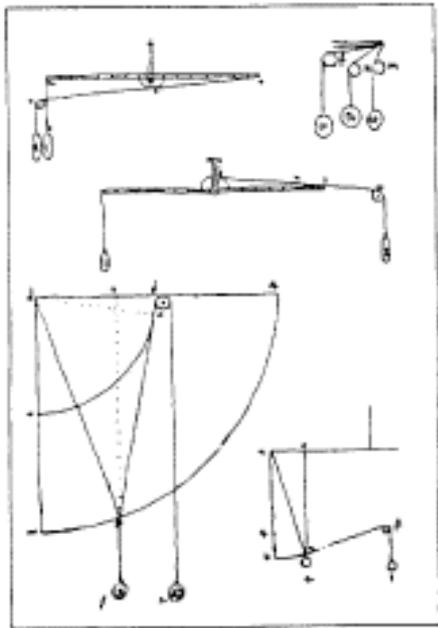
Clearly, whatever knowledge "traditional" teaching methods may have imparted, they have too frequently failed to produce understanding. The use of simple models which demonstrate basic structural concepts with materials like thread, or balsa wood, or paper, are immensely useful. These studies tend to be done in the early years, and the general relevance of their lessons may not always be understood, but for whatever reasons - and many are possible - it is sadly clear from annual degree shows, not to mention the professional press, that the lessons do not always stick.

It is response to this interesting if rather exasperating state of affairs that the DEFLECT project was conceived. As with other interactive, computer aided learning packages, it allows students to proceed at their own pace, whether motivated by a curiosity about what happens if one "does things" to a structure - loads it, pushes it, or changes the material of which it is made, or by "the need to know".

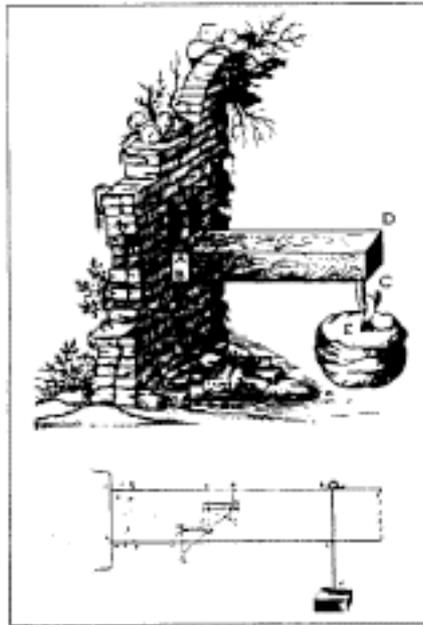
Discussions with engineering colleagues revealed, interestingly, that the problem was by no means confined to architects, and it was felt that such a package would benefit engineering as well as architectural education. Initial student trials have been encouraging, but we shall have to await future degree shows for a fuller story.

### The Modelling And Illustration Of Structural Behaviour

The graphic communication of structural theory has grown greatly in complexity since Leonardo da Vinci's masterly illustrated studies on Equilibrium (Fig 1a), and Galileo's analysis of Force and Moment Equilibrium in a cantilevered beam (Fig 1b, after Sandaker, B.N. and Eggen, P.)<sup>[1]</sup> In nineteenth century France, where the theory and application of iron construction was evolving rapidly, and heated debate raged about the relationship between structure and architecture, the graphic communication of structural ideas was particularly sophisticated, but the advent of computerised calculation and graphics in our time has transformed the field. Not since the invention of children's building blocks has there been quite such a powerfully responsive educational tool for examining the consequences of one's structural decisions as that offered by CAL.



*Fig. 1a*  
*da Vinci's studies and sketches on*  
*Equilibrium*  
*(After Sandaker, B. N. and Eggen, P., 1993)*



*Fig. 1b*  
*Galileo's analysis of Force and Moment*  
*Equilibrium on a cantilevered beam*

Despite the very limited number of mainly computerised structural design tools that aid design, an attempt is made here to review them. For example, the 'Pin, Rigid, Plastic and Grid', programme developed by Gardner<sup>[2]</sup> at Kingston University is a useful programme, but it has not been designed as a tool for teaching and/or learning structures. The programme is written for the DOS rather than the WINDOWS operating system and this limits the possibilities of 'dynamic linking' to and 'object embedding' from other WINDOWS applications such as spreadsheets, word-processing and databases.

The CADS programme<sup>[3]</sup>, on the other hand, is very professional in its outlook and has an attractive user interface, and it can analyse three dimensional as well as two dimensional structures. Its usage in architectural education and practice is, however, hindered by its complexity and incompatibility with the design process.

An interactive programme for structural simulation and design, CASDET (Computer Aided Structural Design Education Tool), aimed at educating architects and civil engineers, has been cited in the literature. Developed by Piccolotto and Rio<sup>[4]</sup> on an HP workstation, it can be ported to a PC running Windows NT, and consists of an interface and five modules (tools). The Graphic tool is a graphic editor that allows students to draw structural members, import and edit pictures. The Structures tool enables the creation and analysis of complex structures and change the properties of structural members. The Mathematical tool enables mathematical operations to be performed. The CAI-tool provides teachers with standard methods on how to create computer based exercises on structures. The Video-tool is for animation and visualisation, and can present laboratory experiments on members and show photorealistic images of existing buildings and structures. The 3-D tool, the most advanced module, allows the creation of 3-D objects and the exploration of the behaviour of skeletal structures in space.

### The DEFLECT Programme

The uses of computers in education have increased greatly since the 1960s. Their role has been categorised under three headings.<sup>[5]</sup>

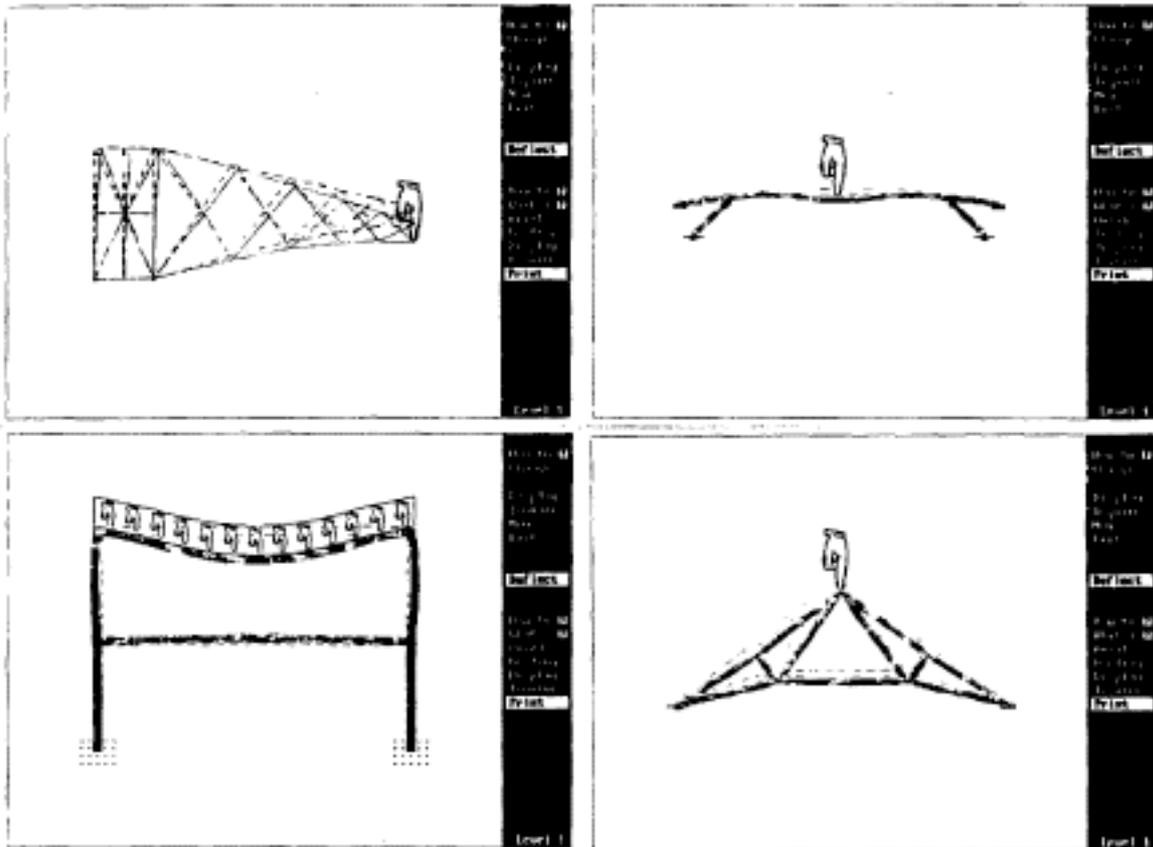
- a) As a 'supercalculator' for performing complicated and time consuming calculations
- b) As a teaching tool for computer programming
- c) As an aid to the interactive teaching/learning process: in this computers have made a major contribution to education. In computer aided learning (CAL) the computer can be used in two modes: as a 'substitute tutor' and as a 'simulated laboratory'. In the first mode the student participates in an interactive dialogue with the computer, i.e. direct instructional device. In the second mode, the student performs experiments on a model programmed into the computer. This mode allows students to study the response of the system following changes to important variables. The DEFLECT programme for structural design and analysis falls under the second mode of CAL.

The aim of DEFLECT is to create an interactive environment for learning and teaching structures to students of Architecture and Civil Engineering. It will enhance students' understanding of how structures respond to and behave under load. It will also enable students to investigate the effects of changing materials, section sizes, and overall geometry, on the deflection of the structural form. The programme has a graphical user interface with one right hand menu leading to sub-menus, an on-line help file on how to operate the software, and a second help file (What is) which explains basic structural concepts in a simple manner. The programme consists of three levels.

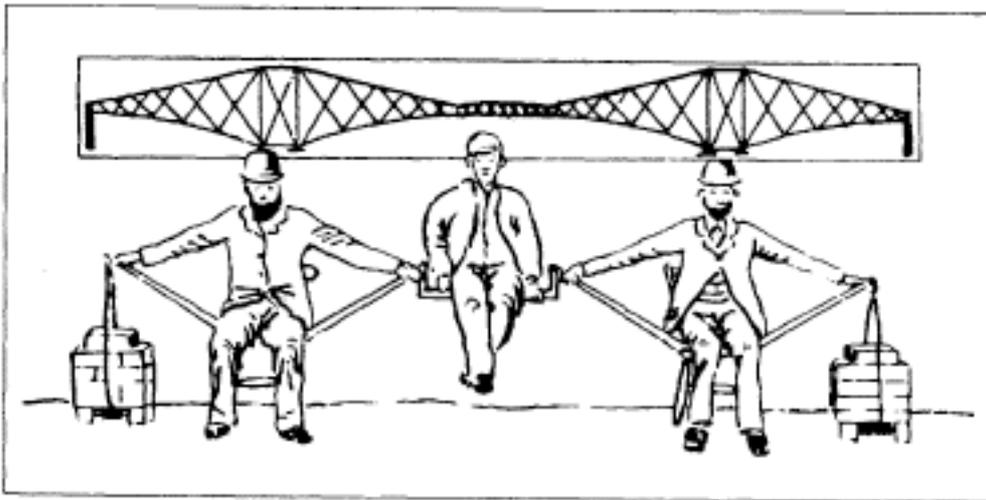
#### **Level 1 (Example Structures): effects of applying loads on pre-defined structures:**

As a 'learning resource', this level allows students to examine the behaviour of pre-defined structures under load, and to explore the effects of changing key variables, i.e. loads, joints and supports, on the deflection of the structural form. Members which are in tension and compression can be identified easily.

This level has four screens of pre-set structures (Fig. 2), including classics like the Forth Bridge.



*Fig. 2 One of the screens in Level 1 of the DEFLECT programme with Part of the Forth bridge as a pre-set structure under load.*



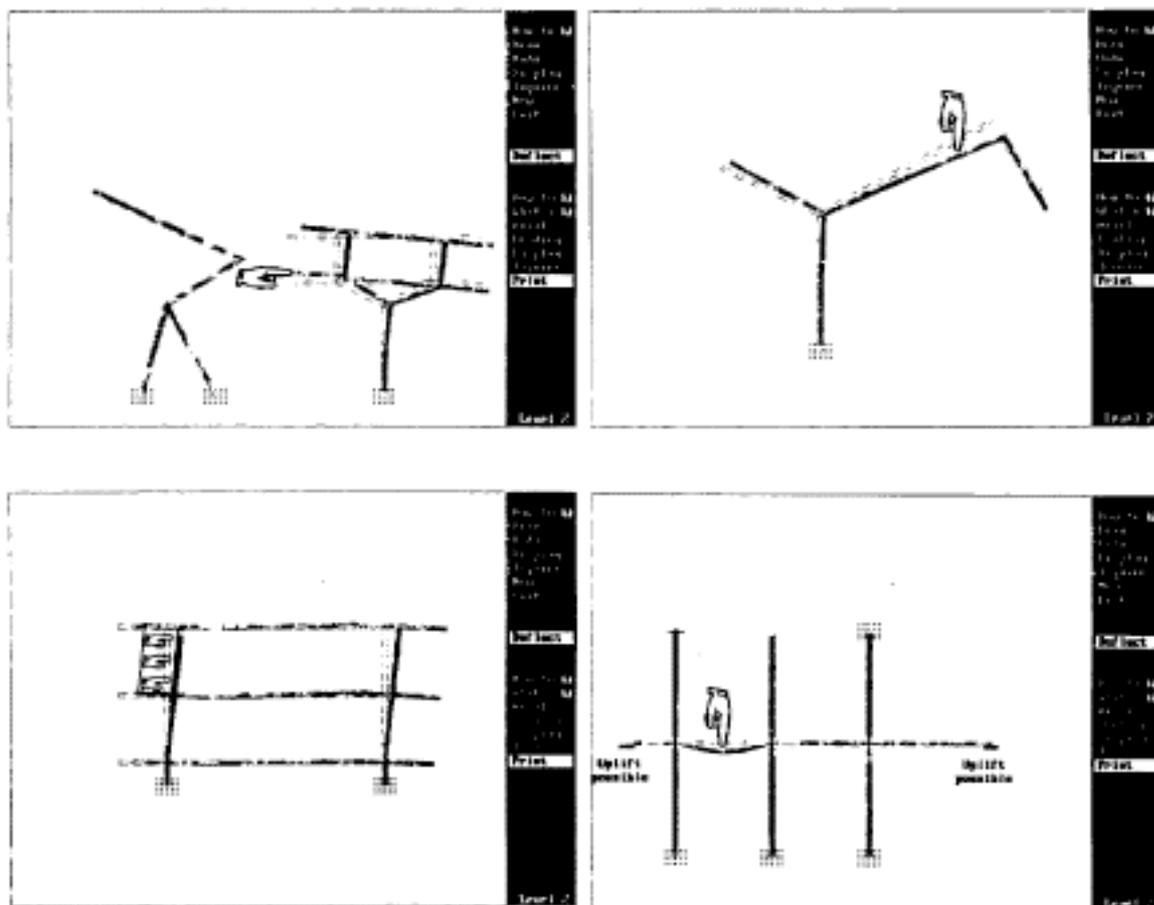
*Fig. 3 Demonstration of the Structural Principle of the Forth Bridge*

**Level 2 (Draw Your Own Structure): effects of applying loads to user-defined structures:**

The facilities provided by this level can be used as a learning and teaching resource, where students can be asked to investigate a structural design problem and arrive at a solution.

A graphical interface permits students to draw their own structures and investigate structural deflection under load. The effects of changing key parameters on deflection can also be studied. Applying different joints, supports and loads to structural members will produce various types of 'mechanisms' that the software can identify as 'stable' or 'unstable'. Areas of tension and compression within a structural member are very well highlighted using a colour scheme. While the positioning of 'point' load is confined to the quarter point, mid span and the end point of a structural member, the 'uniformly distributed load' is automatically adjusted over the full length of the member.

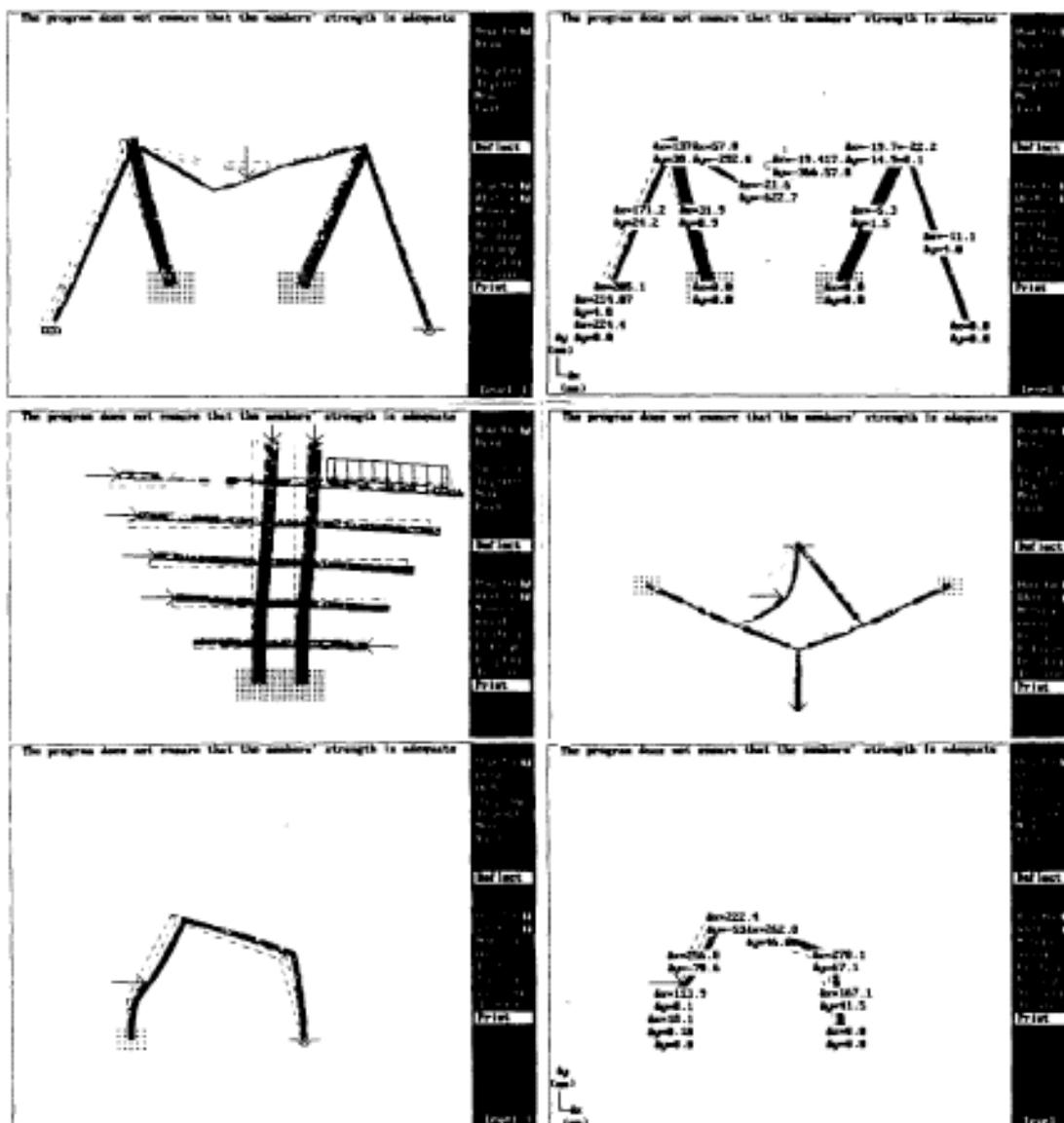
Drawing aids such as Grid and Snap can be displayed on and off, and their value can be changed. Dynamic animation of loaded structures is also possible, and two magnification options (zoom in/zoom out) are available. Figure 4 shows some features of this level.



*Fig. 4 Level 2 allows Students to draw their own designs and examine their deflection under load.*

**Level 3 (Real Materials and Real Loads): Deflection values for user defined structures with variable properties:**

At this level, students can give real dimensions to structural members, specify cross sectional properties and materials. The type of joint between complete members (where materials and cross-sectional properties are specified) is automatically determined by the software according to common practice in real life situations. Four types of materials can be assigned to members: Concrete, Steel, Masonry and Timber. Members are of two types: Planar and Linear. A library of cross sectional sizes of members for each of the four types of materials is also supplied. Loads can be specified by the student and applied to structures at specific positions. Animated deflections can be generated with deflection values for each member displayed at mid-span and both ends. The displayed deflection can be exaggerated using the 'Enlarge' command. Figure 5 shows some worked examples.

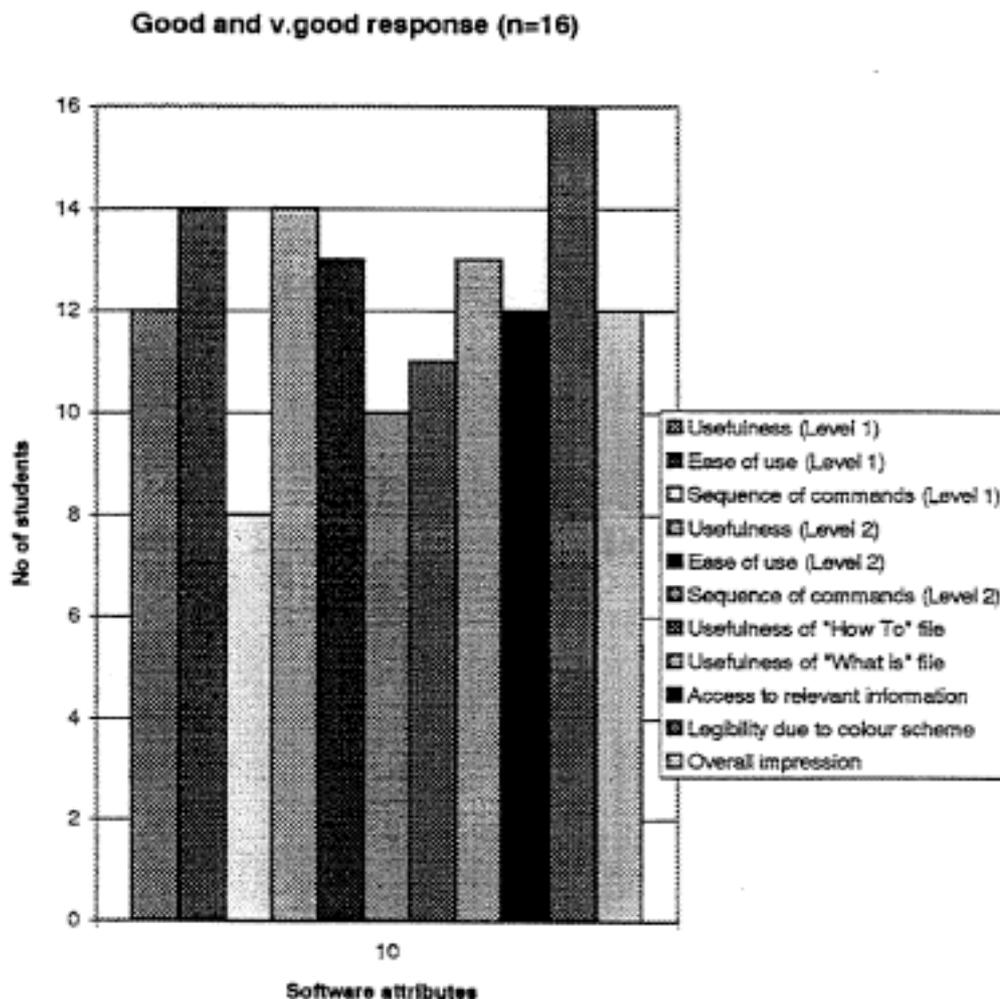


*Fig. 5 Level 3 enables the Construction of Real Structures with Materials*

### Software Evaluation: Student Trials

Before finalisation, the software was appraised by student from both institutions and their comments provided useful feedback for improvement. The appraisal was intended to investigate a number of key issues regarding the value of the software as a CAL package for teaching structures, its usefulness, and the ease of use, i.e. interaction with the interface. Questionnaires were administered to six groups from 1st year engineering studies at Paisley University, and to 16 students from the 2nd year at the Mackintosh School of Architecture. Students' knowledge of deflection, tension and compression was assessed before and after using the software, and their attitudes towards the software were measured. Results of assessment from Paisley University confirmed that the programme was a very good teaching tool, particularly when combined with structured exercises. Students also showed a great deal of satisfaction with the software image and ease of use.<sup>[6]</sup>

Results from the Mackintosh showed that students regarded the software as an extremely useful tool for teaching and learning structures. They found the 'What is' file an excellent learning resource on structures. Twelve out of sixteen students rated all the software attributes as 'good' or 'very good'.



*Fig. 5 Students' response to the software (the Mackintosh School)*

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R. Hardy, D. Wilson and D. Crowther (Paisley University)  
Professor C. MacCallum and Dr. R. Hanna (Mackintosh School of Architecture)  
T. Craddock and N. Dowdey (Lamp Software)

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